NPS55JS75061

# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

A REPRESENTATIVE DEFENSE CONTRACTOR

MODEL SPECIFICATION I

by

Carl Russell Jones

The Systems Acquisition Research Program

June 1975

Approved for public release; distribution unliminted.

Prepared for:

Chief of Naval Research
Arlington, VA 22217

FEDDOCS
D 208.14/2:NPS-55JS75061

NAVAL POSTGRADUATE SCHOOL
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The work reported herein was supported both by the Foundation Research Program of the Naval Postgraduate School with funds provided by the Chief of Naval Research as well as funds provided directly from the Chief of Naval Research (Code 430).

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NPS 55JS 75061
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): A Representative Defense Contractor: Model Specification I
5. TYPE OF REPORT & PERIOD COVERED: Final Report for January 1975-April 1975. Partial Report April 1975 - July 1975.
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Carl R. Jones
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Postgraduate School, Monterey, California 93940 CODE 55Js
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61153N; RR 014--07-01 NR047-134; N0001475WR50239
11. CONTROLLING OFFICE NAME AND ADDRESS: Chief of Naval Research, Arlington, Virginia 22217
12. REPORT DATE: June 1975
13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Defense Contractor
Economic Analysis
Systems Acquisition
DOD Procurement
Financial Management

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A model is specified of a representative defense contractor. The contractor is assumed to maximize the expected utility of managerial emoluments, performance of the contractor's product and corporate annual net income over a finite planning horizon. This maximization is constrained by the technology of research and development, test and evaluation, manufacturing and a centralized warehouse-inventory operation. There are commercial sales as well as a number of on-going and potential DOD projects. An extensive accounting

model of the contractor is included. Corporate financial management involves the issuing and retiring of short- and long-term debt and equity in addition to the choice with respect to dividends and retained earnings.

The inputs of the contractor include plant and equipment (both contractor and government supplied in T&E), engineering support labor (both contractor and government supplied in T&E), administrative labor, manufacturing labor, weapon system operators (both contractor and government supplied in T&E), material, purchased parts, subcontracted items, and government furnished items. The outputs are a homogeneous product for commercial sales in a competitive market and weapon systems for sale to the government in rivalrous markets for "new" proposals and a bilateral monopoly market in the case of sole sourcing.

Risk is introduced by considering each possible alternate event due to such factors as rivals' actions, technological risk, capital market conditions and variation in government and commercial sales to be grouped in states-of-nature. Thus, the contractor is assumed to plan for a variety of future state-of-nature (contingencies) and chooses a complete plan (inputs, outputs, financing, proposal bids, etc.) for each contingency.

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# I. INTRODUCTION AND OVERVIEW

## A. Preliminaries

Since the beginning of the United States, the military services have been contracting for supplies and services of many types. Throughout this period the military departments and now the Department of Defense (DOD) have been asked by Congress and the public to not only be a customer of needed supplies and services, and hence a possible monopsonist, but also to be a regulator of contractor conduct. As a result of this public interest, there has been much effort devoted over the years to understanding the DOD-industry relationship -- some of it partisan, some of it scientific. Both types of effort have also spanned the multitude of goods and services acquired by DOD from industry. This paper is intended as a contribution to the scientific literature concerned with the acquiring of major weapon systems.

Ideally, it would be desirable to have a complete model of the systems acquisition process. To accomplish this end, submodels of various aspects of the process are needed. Of particular interest is a submodel of a large defense contractor who is the prime contractor on one or more systems as well as having other defense contracts or subcontracts. In addition, some commercial business is part of the contractor's activities. Examples which come to mind are Lockheed, McDonald-Douglas, Boeing, General Dynamics, Litton and Todd Shipyards.

Specifically, this paper focuses on the conduct of an "ideal" prime contractor within the structure of weapon systems acquisition process.

## B. The Defense Contractor Literature

As mentioned, there have been many separate studies of the DOD-industry relationship. For example, there have been the Congressional Commission on Government Procurement, the Sub-committee of the Industry Advisory Council (IAC) to Consider Defense Industry Contract Financing, and most recently, the Material Acquisition Review Committees for each service. And, of course, this is just the official side with undoubtedly at least as many studies completed or underway by those outside government circles. An interesting compilation of some of the more analytical efforts to understand the so-called Military-Industrial complex is contained in the monograph edited by Steven Rosen entitled "Testing the Military-Industrial Complex" (8). It is interesting to note that these studies, whether from within or without official circles, do not contain a detailed model of a contractor which could be useful for understanding a contractor's response to changes from outside the organization as well as to changes from inside the organization. Whether this is a failure of the approach or the result of the lack of research interest or funds is not possible to ascertain. However, it is the case that from this literature it is not possible to understand the contractor's current or possible response to structural changes in government procurement practices.

However, there is a body of literature oriented more towards the detailed modeling of certain aspects of contractors. Mathematical programming formulations based on expected utility theory have been directed toward the effect of incentive contracts on contractor behavior and toward the determination of an optimal bid when rival contractors are also attempting to secure a given contract.

In the Scherer-Cross-McCall-Canes development [(10), (5), (7), (4)] the essential idea revolves around the contractor being risk neutral and interested in maximizing profits on both governmental and commecial business by choosing a contract price (bid). At the current stage of development this line of thought indicates that contractors should be expected to concern themselves with both the bid and the share rate on costs and that inefficient firms only win contracts if the government weighs low bids much more than high share rates in its decision calculus. But the models indicate that fixed price incentive contracts could be awarded to inefficient contractors. A major drawback of this effort is that it only deals with a simple profit calculation of revenue minus costs and hence, for example, cannot be used to understand contractor behavior with respect to production and financing. That is, in its present form, it is too limited in scope to be of great help in providing an understanding of contractor's conduct.

The Barron [(1), (2)] work accepts most of the basic model structure of the Scherer-Cross-McCall-Canes line of thought, but changes the assumption of risk neutrality on the part of the contractor to one of risk aversion. This idea of risk aversion on the part of a business form is also seen in other recent works in economics, for example, the works of Leland (6) and Sandmo (9). Essentially the effect of risk aversion on the part of the contractor is to lower the bid (contract price) and thus the most risk-averse contractor, ceteris paribus, appears as the most efficient. As, in the case of the other line of development, a chief drawback of the Barron efforts is the limited scope of the model for understanding a contractor's conduct.

However, expanding the scope of any model of a contractor leads to an extremely complex model. Vickers (11) has attempted to provide a model that integrates production, finance and market structure within the context of a risk-averse expected utility of profit maximizer. However, he presents the model in various stages of complexity and never does quite provide the overall integration attempted. Partly this is due to technical errors and partly to the nature of the phenomenon under study. Since it is the goal to provide an understanding of a "real world" firm (in the case at hand, a defense contractor) much of the special nature of that particular industry and the government itself must be included. While this means additional modeling complexities, it also means that it is not necessary to deal with many phenomenon of interest elsewhere in the economy. Thus the author suggests that in attempting to understand behavior, the researcher is better off concentrating on the firm in the context of a particular industry. And that is the case in this report which contains a specification of a model of a defense contractor.

In general, a defense contractor who is a prime contractor is involved with research and development, test and evaluation, and governmental and commerical production activities in a world of uncertainty and rivalry. Such a contractor must plan, at the corporate level, for a multitude of contingencies over the firm's planning horizon. In addition, a defense contractor is involved with the financial side of the business. This aspect, a flow of funds constraint on his actions, means a concern with such areas as accounting rules and systems, the money and capital markets, governmental and commercial customer payments, and its own payments for inputs. Illustrations of the importance of such financial areas can be found in the Lockheed loan guarantee and the Grumman use of Navy progress payments in the money market. Finally, the contractor must manage the physical and financial aspects of the corporation so as to further the objectives of the firm. To understand the contractor's conduct, it is necessary to consider all these elements of the corporation. The detailing of the model in all these areas is the subject of the rest of this report, with an overview of the model in the next section.

## C. An Overview of the Model

The representative defense contractor is modelled as having a management which prefers to maximize the expected utility of managerial emoluments, weapon system performance attributes, and the accounting net income in each of the time periods between the current period and finite planning horizon. This risk-averse management is constrained by the existence of current and possible future DOD project business as well as the existence of current and possible future commercial business. Each DOD project can have either a research and development, test and evaluation or manufacturing phase or any combination. In general, the contractor is assumed to have a project organization except for a central warehouse-inventory operation. For simplicity, commercial operations are of a manufacturing nature only. Each of the DOD projects and commercial manufacturing are assumed to be governed by organizational and physical laws such that they may be represented by a function that relates inputs to outputs: a production function or technology.

The contractor is assumed to have an extensive accounting system that permits all economic and physical transactions during a given period to be related to the balance sheets and income statements of that and later periods. The accounting rules are adoptions for the model of those in use in defense contractors for DOD and commercial business.

The contractor is also assumed to have a quite active financing activity. This activity is involved with the issuing and retiring of both short and long term debts, the issuing of equity, and the decision between dividends and retained earnings. All these financial management activities are decision variables to the contractor's management given the corporate objective function and the structure of the money and capital markets. In order to keep the complexity of the overall model within a reasonable bound, the money and capital markets are assumed to be efficient and representable as purely competitive. Thus, future comparative statics analysis (sensitivity analysis) as well as empirical work is of importance. It should be noted that progress payments received on DOD contracts are part of the corporate financial management picture. Thus there is an interaction from progress payment availability to contract price (bid) on future work, that provides an incentive for securing a contract over and above the incentives embodied in the work itself.

The physical inputs include engineering labor, engineering support labor, administrative labor, manufacturing labor, corporate headquarters labor and system operators. Note that during Test and Evaluation activities both the contractor and DOD supply engineering labor, engineering support labor and system operators. Also there are plant and equipment, material, purchased parts, subcontracted parts, and government furnished parts as inputs. In some cases these input market structures are represented as competitive, but in others, e.g., subcontractors and interactions with the DOD representation is via a rivalrous model.

Finally, the regulation of the contractor by DOD is embodied in the model by including the relevant features of the Armed Forces Procurement Regulations for each separate DOD contract whether current or future and the contractor's perception of its government business regulation by the Renegotiation Board, General Accounting

Office, congressional committees and the like.

While the word used in the above paragraphs do not capture the idea of risk in any of these activities, it is included in the model. This is done by considering that a finite number of conceivable events could occur, e.g., technological risk, demandshift risk, capital market risk and rival's action risk. Then these time dated risks are combined into alternative states of nature over which the contractor's management is presumed to have preferences. Thus, the management is presumed to choose the magnitude of all decision variables in each of the alternative states of nature (contingencies) as its strategic plan over the planning period. Thus the issues of multilevel decentralized planning are left for future research. Rather the strategic plan is characterized in this paper.

## D. Organization of the Report

In Chapter Two the details of the representative defense contractor with particular emphasis on aerospace are specified. For ease of exposition the overall model is divded into submodels which are specified in turn. The Table of Contents may be used to identify the submodels used and their location with the chapter. In the last section of the chapter, the overall model is formally written as a mathematical programming problem with the constraint in most cases represented in generic form only. Chapter Three, the final chapter in this report, contains a general discussion of Specification I of the model with some emphasis on modifications of interest that could lead to a Specification II. Future reports that will discuss the contractor's optimal decision rules and response to various outside influences (comparative statics analysis) are also discussed.

# II. MODEL SPECIFICATION

## A. Preliminaries

In this section of the chapter, the discussion will focus on the preliminary material necessary to develop the submodels. Mainly this material concerns the modeling of time and risk as well as the anticipated contract structure over the planning period.

As indicated in Chapter One, the model is developed assuming that the contractor has a finite planning horizon and expects a finite number of possible futures (alternative states of nature). Thus, uncertainty or at least risk is included by utilizing a finite number of possible states of nature, and time is considered as a finite number of discrete periods. These will be denoted by subscripts $s$ and $t$ respectively.

In considering the future the contractor has anticipations concerning the completion of existing government contracts, the awarding of future contracts and, in general, the activities associated with each contract. There is also an anticipation concerning the level of commercial sales in each of the future periods. In order to formalize these ideas it is assumed that there exists a set of specific government contracts and commercial sales. This anticipation of future business is shown in Figure II-1. This figure is drawn so as to highlight the time phasing of the government contracts and commercial sales as well as the general class of activity in each time period. The figure is drawn with some contracts currently ongoing, some begin and end during the planning period, and others begin but are still ongoing at the end of the planning period. Also while the majority of the government contracts include the usual three activities of Research and Development (R&D), Testing and Evaluation (T&E) and Manufacturing (PROD), there are "pure" research and development contracts and "pure" testing and evaluation contracts. For simplicity no "pure" manufacturing contracts are shown. The manufacturing of commercial products goes on over the entire planning period. This framework can be used whether the contracts are with DOD, with another contractor (subcontract) or with another firm in a team arrangement.

For simplicity of notation, it is assumed that each of these contracts will "exist" in each of the possible states-of-nature. However, the contractor's subjective estimate of the likelihood of winning future contracts will not be the same in the possible states-of-nature. This permits the model to incorporate the various aspects of business or income stream risk without a cumbersome notation.

In many cases, the same input is used in a variety of operations. In this case, the variable will be subscripted to denote the use. For example, plant and equipment services tends to be used in all activities so that its use in research and development is denoted ${}_{R}k$.

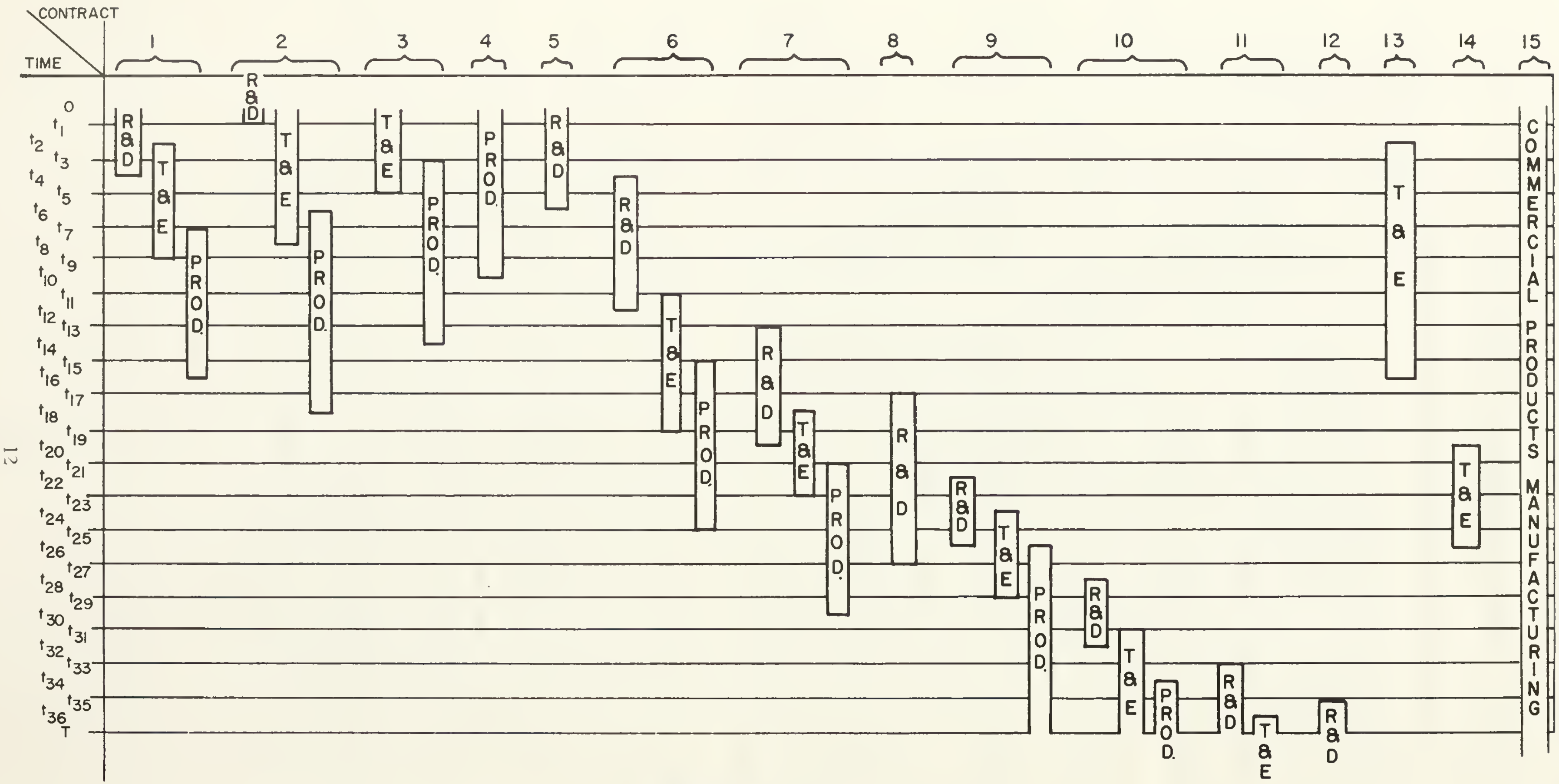


FIGURE II-1

TIME ACTIVITY STRUCTURE OF FUTURE CONTRACTOR BUSINESS

## B. The Research and Development Submodel

As the time-activities structure (Figure 2-1) is drawn there is a research and development activity as part of most of the government contracts. This is intended to highlight the prime contract nature of the defense contractor. This section contains the exposition of the structure of the model of that activity.

It is the writer's view that there is a technology involved in the research and development process itself. That is, both from the physical science and organization theory viewpoints there exists methods of combining engineers, technicians, administrators, labs, model shops, draftsmen, designers, desks, and buildings to produce an engineering design. The human skills include engineering and organizational knowledge as well as knowledge of mil standards and specifications. That design is observed as blueprints, reports, prototypes, and planned system attributes. For the purpose of this paper, this research and development process has been modeled as shown schematically in Figure II-2. This physical and organizational view of technology will be applicable to all the production processes of the firm. To reduce the complexity of Model Specification I, it will be assumed that the technology of the research and development process itself will not change over the planning horizon nor will it be event (state-of-nature) dependent. Rather the riskiness in production (transformation) processes will be embodied with the inputs and outputs of the process, i.e., in the technology embodied in the weapon systems themselves.

As shown on the schematic and neglecting risk for the moment the research and development operations transform the inputs of contractor engineering labor (${}_R x_1$) contractor engineering support labor (${}_R x_2$), administrative labor (${}_R x_7$), plant and equipment services (${}_R k$), material from inventory (${}_R \psi_4$), purchase parts from inventory (${}_R \psi_3$), subcontracted parts from (${}_R \psi_2$) and government furnished parts from inventory (${}_R \psi_1$) into prototype hardware (${}_R \psi_5$), production drawing (${}_R \psi_6$) and planned system performance attributes ($\psi_7, \psi_8, \ldots, \psi_A$). The transformation process, the tecnology of research and development is represented by an implicit function as follows:

$$H({}_R\psi_5, {}_R\psi_6, \psi_7, \psi_8, \ldots; \psi_A; {}_R x_1, {}_R x_2, {}_R x_7, {}_R k, {}_R\psi_4, {}_R\psi_3, {}_R\psi_2, {}_R\psi_1) = 0.$$

This implicit function is assumed to have the following mathematical properties.

(1) $H(\cdot)$ is continuous.

(2) $H(\cdot)$ has continuous second derivatives.

(3) The second cross derivatives for any pair of variables are equal.

$$\frac{\partial^2 H}{\partial r \partial s} = \frac{\partial^2 H}{\partial s \partial r} \qquad s, r = \psi_1, \psi_2, \psi_3, \psi_4, \psi_5, \psi_6, \psi_7, \psi_8, \ldots, \psi_A, x_1, x_2, k$$

The variable (inputs and outputs) of this submodel are mostly either outputs of some other submodel or the inputs to some other submodel. The exception is the planned system performance attributes. In the case of a "pure" research and development contract these are the main outputs and are "delivered" to the government as the final product. In the case of "complete" projects with test and evaluation and manufacturing phases they constitute an intermediate output for use by the contractor and the government in comparison with contract specifications for the purpose of reallocating resources during the life of the contract. The sequential

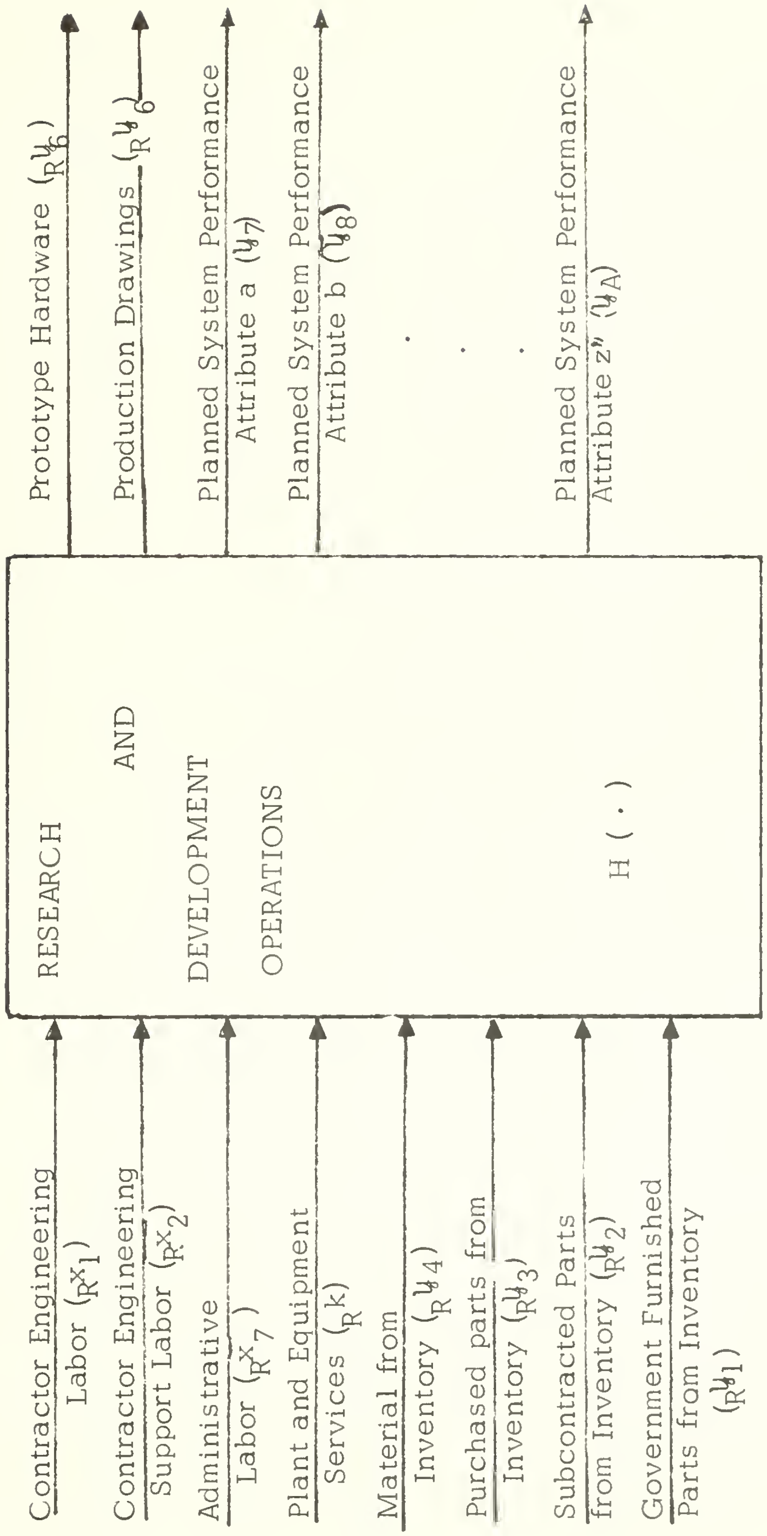


Figure II-2

Schematic of the Research & Development Submodel decision making aspect of this reallocation process is not considered in this particular paper.

So far this submodel has been discussed without considering the time structure of a specific contract or the risk associated with research and development. In order to permit the inclusion of time it is only necessary to time date each of the inputs and outputs (subscript $\underline{t}$). To make the overall model more understandable it is assumed that inputs in period $\underline{t}$ are transformed into outputs in the same period. As mentioned before the technology of research and development is assumed to be time invariant. The risk aspects are modeled by considering each alternative possible outcome as a different state-of-nature. That is, in say one of the possible futures, the contractor has a technological breakthrough which permits the contract specifications to be met and exceeded well within the resources available. In another future the opposite may occur. Each of these features is a different state-of-nature and denoted by the subscript $\underline{s}$ which is used with each input and output. As a first approximation the technology of research and development is assumed riskless, rather the risk is embodied in the inputs and outputs of the technology.

Finally, the research and development contracts are contract specific so it is necessary to use a subscript $\underline{c}$ to denote the contract. It is assumed that not only the inputs and outputs are contract specific but that a different research and development technology is possible on each contract. Thus, the research and development production function is subscripted by contracts.

In equation form the completed submodel is

$$H_c\Big([{}_{cR}y_{5ts}];[{}_{cR}y_{6ts}];[{}_{c}y_{7ts}];[{}_{c}y_{8ts}];\cdots;[{}_{c}y_{Ats}];$$
$$[{}_{cR}x_{1ts}];[{}_{cR}x_{2ts}];[{}_{cR}x_{7ts}];[{}_{cR}k_{ts}];[{}_{cR}y_{4ts}];$$
$$[{}_{cR}y_{3ts}];[{}_{cR}y_{2ts}];[{}_{cR}y_{1ts}]\Big) = 0$$

where

(1) [ ] denotes a vector

(2) $c = 1, 2, \cdots, C$

(3) $t = 1, 2, \cdots, T$

(4) $s = 1, 2, \cdots, S$

(5) R represents the use of the input or the production of an output in research and development operations.

Finally, note that with respect to this submodel, the corporate management chooses the quantity of each input and output in each time period, on each contract and in each state-of-nature subject to the technological restraints of the research and development process itself.

## C. The Test and Evaluation Submodel

As the time-activities structure is drawn (Figure II-1) there is a test and evaluation activity as part of most government contracts. This section will explain the structure of the model of that activity.

In the author's view there exists a technology based on physical science and organization theory that permits out understanding of the process by which engineers (some contractor furnished, some government furnished), technicans (some contractor furnished, some government furnished), prototypes, parts and material (some furnished by the government) and operators (some government, some contractor) are combined to produce measurement of actual system performance. In this paper this test and evaluation process is modeled as shown schematically in Figure II-3.

As shown on the schematic, the test and evaluation operations transform prototype hardware $({}_T\psi_5)$, system operators $({}_Tx_{15})$, engineering labor $({}_Tx_{13})$, engineering support labor $({}_Tx_{14})$, plant and equipment services $({}_Tk)$, administrative labor $({}_Tx_7)$, material from inventory $({}_T\psi_4)$, purchased parts from inventory $({}_T\psi_3)$, and government furnished parts from inventory $({}_T\psi_1)$, into measured

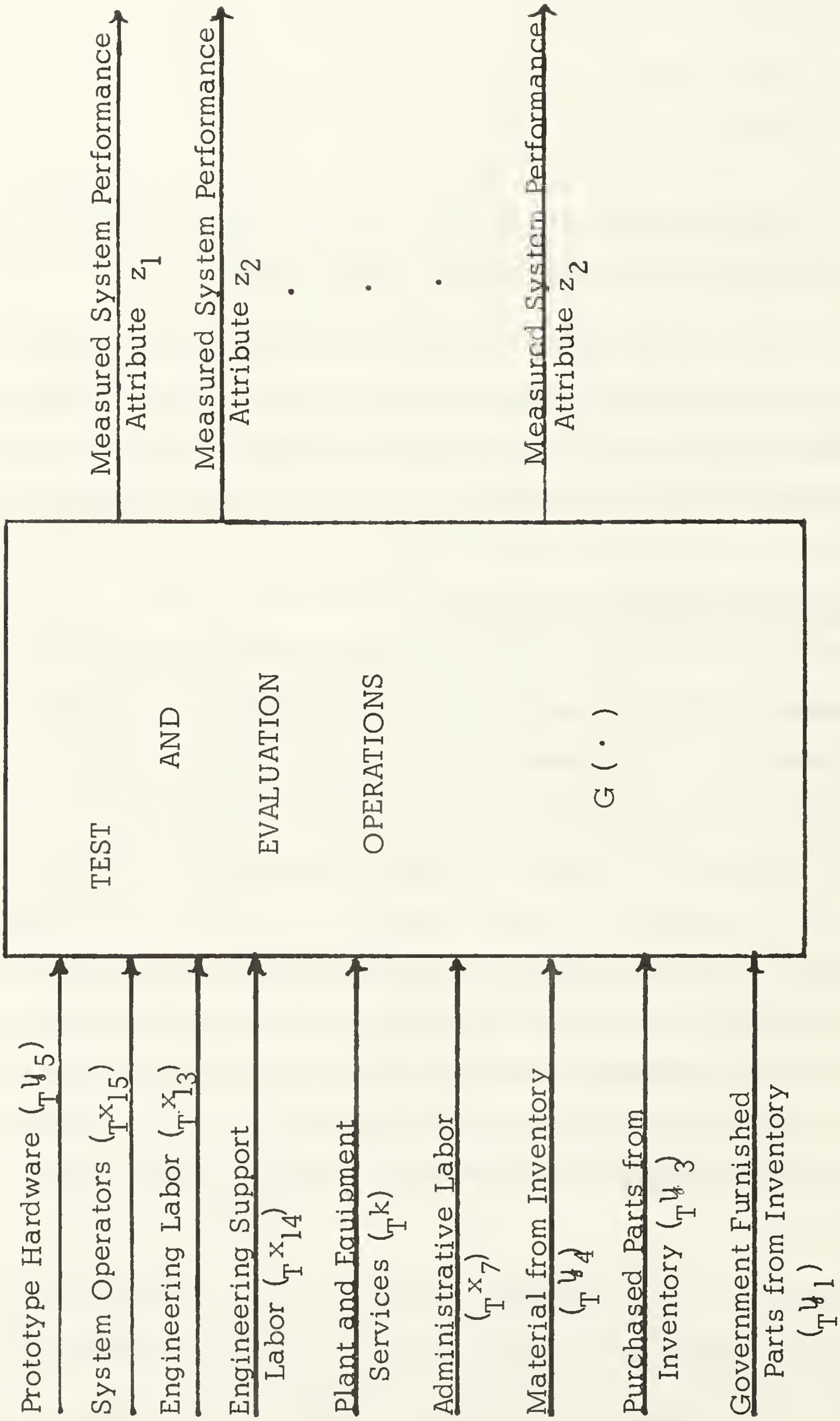


Figure II-3

Schematic of the Test and Evaluation Submodel system performance attributes $(z_1, z_2 \cdots, z_B)$. The transformation process, the technology of test and evaluation, is represented by an implicit function as follows:

$$G(z_1, z_2, \cdots, z_B; T^{y}_5, T^{x}_{15}, T^{x}_{14}, T^{x}_{13}, T^{k}, T^{x}_7, T^{y}_4, T^{y}_3, T^{y}_1) = 0$$

This implicit function is assured to have the following mathematical properties.

(1) $G(\cdot)$ is continuous.

(2) $G(\cdot)$ has continuous second derivatives.

(3) The second cross derivatives for any pair of variables are equal:

$$\frac{\partial^2 G}{\partial r \partial s} = \frac{\partial^2 G}{\partial s \partial r} \qquad s, r = z_1, z_2, \cdots, z_B, T^{y}_5, T^{x}_{15}, T^{x}_{13}, T^{x}_{14}, T^{k}, T^{x}_7, T^{y}_4, T^{y}_3, T^{y}_1$$

The inputs to this submodel are the outputs of other submodels. The outputs, measured system performance attributes, are a final product for use by the government. That is, the systems that are delivered from the manufacturing operations will tend to possess the measured attributes. Variations in the production process and measurement errors are modeled by considering each of these to be a separate state-of-nature (i.e., alternative future). The measured attributes are also used to compute the incentive profits (loses) for the specific contract.

As in the previous submodel, time and risk matters are incorporated by indexing the variables with respect to the time period and the state-of-nature. Again the technology of test and evaluation is assumed to be time invariant and state-of-nature invariant. It is assumed to be contract specific, however.

In equation form the complete submodel is

$$G_c\left([{}_c z_{1ts}], [{}_c z_{2ts}], \cdots, [{}_c z_{Bts}]; [{}_{cT} x_{15ts}], [{}_{cT} x_{14\,ts}], [{}_{cT} x_{13ts}], [{}_{cT} k_{ts}], [{}_{cT} x_{7ts}], [{}_{cT} \psi_{4ts}], [{}_{cT} \psi_{3ts}], [{}_{cT} \psi_{1ts}]\right) = 0$$

where

(1) [ ] denotes a vector.

(2) $c = 1, 2, \cdots, C$

(3) $t = 1, 2, \cdots, T$

(4) $s = 1, 2, \cdots, S$

(5) T represents the use of an input in test and evaluation operations.

In addition to the above discussion, it is convenient to include at this point a discussion of the interal to the firm balance aspects of prototype hardware. This item is supplied by the research and development activity and used by the test and evaluation activity. The quantity supplied must not be exceeded by that demanded for use if the corporate system is to have consistency.

Symbolically,

$$R\psi_5 \geqq T\psi_5$$

and if all time, contract and state-of-nature indices are included it is

$${}_c R\psi_{5ts} \geqq {}_c T\psi_{5ts}$$

where

$c = 1, 2, \cdots, C$

$t = 1, 2, \cdots, T$

$s = 1, 2, \cdots, S$

R = research and development

T = test and evaluation

Finally with respect to this submodel, the corporate management chooses the quantity of each input and output in each time period, on each contract, and in each state-of-nature subject to the technological restraints of the test and evaluation process itself.

## D. The Manufacturing Submodel

As indicated in Chapter One as part of some of the contracts with the government, there are manufacturing operations. This section contains the exposition of the structure of the model of that activity.

In general, manufacturing is the combining of such inputs as labor, material, and physical capital into a product that is delivered to the government. It is this writer's hypothesis that there is sufficient regularity to the physical and human interactions during the production process to represent the process as the typical economic production function. A schematic of the specific manufaturing submodel used in this paper is shown as Figure II-4.

As shown on the schematic the manufacturing operations transform production drawings (${}_M\psi_6$), plant and equipment services (${}_Mk$), material from inventory (${}_M\psi_4$), purchased parts from inventory (${}_M\psi_3$), subcontracted parts from inventory (${}_M\psi_2$), government furnished parts from inventory (${}_M\psi_1$), administrative labor (${}_Mx_7$), and manufacturing labor (${}_Mx_8$) into completed systems delivered to the customer (q). The transformation process, the technology of manufacturing, is represented by an implicit function as follows:

$$F\,(q;\ {}_M\psi_6,\ {}_Mk,\ {}_M\psi_4,\ {}_M\psi_3,\ {}_M\psi_2,\ {}_M\psi_1,\ {}_Mx_7,\ {}_Mx_8) = 0$$

This implicit function is assumed to have the following mathematical properties.

(1) F (·) is continuous

(2) F (·) has continuous second derivatives

(3) The second cross derivatives for any pair of valuables are equal

$$\frac{\partial^2 F}{\partial r \partial s} = \frac{\partial^2 F}{\partial s \partial r} \qquad r, s = q, M^{\psi}_{6}, M^{k}, M^{\psi}_{4}, M^{\psi}_{3}, M^{\psi}_{2}, M^{\psi}_{1}, M^{x}_{7}, M^{x}_{8}$$

The inputs to this submodel are the outputs of other submodels. The output, completed systems delivered to the customer, are a final product. The quantity of completed systems delivered is not known with certainty. Rather in alternative states-of-nature (alternative futures) in a given time period, the actual quantity delivered is possibly different. This quantity delivered is also used to calculate incentive profit (loses) based on schedule matters for a specific government contract.

As in the previous submodels, time and risk matters are incorporated by indexing the variables with respect to the time period and the state-of-nature. The technology of manufacturing is assumed to be time and state-of-nature invariant. It is assumed to be contract specific.

In equation form the completed submodel is

$$F_c \; [{}_{c}q_{ts}]; [{}_{c}M^{\psi}_{6\,ts}], [{}_{c}M^{k}_{ts}], [{}_{c}M^{\psi}_{4ts}], [{}_{c}M^{\psi}_{3ts}], [{}_{c}M^{\psi}_{2ts}], [{}_{c}M^{\psi}_{1ts}], [{}_{c}M^{x}_{7ts}], [{}_{c}M^{x}_{8ts}] = 0$$

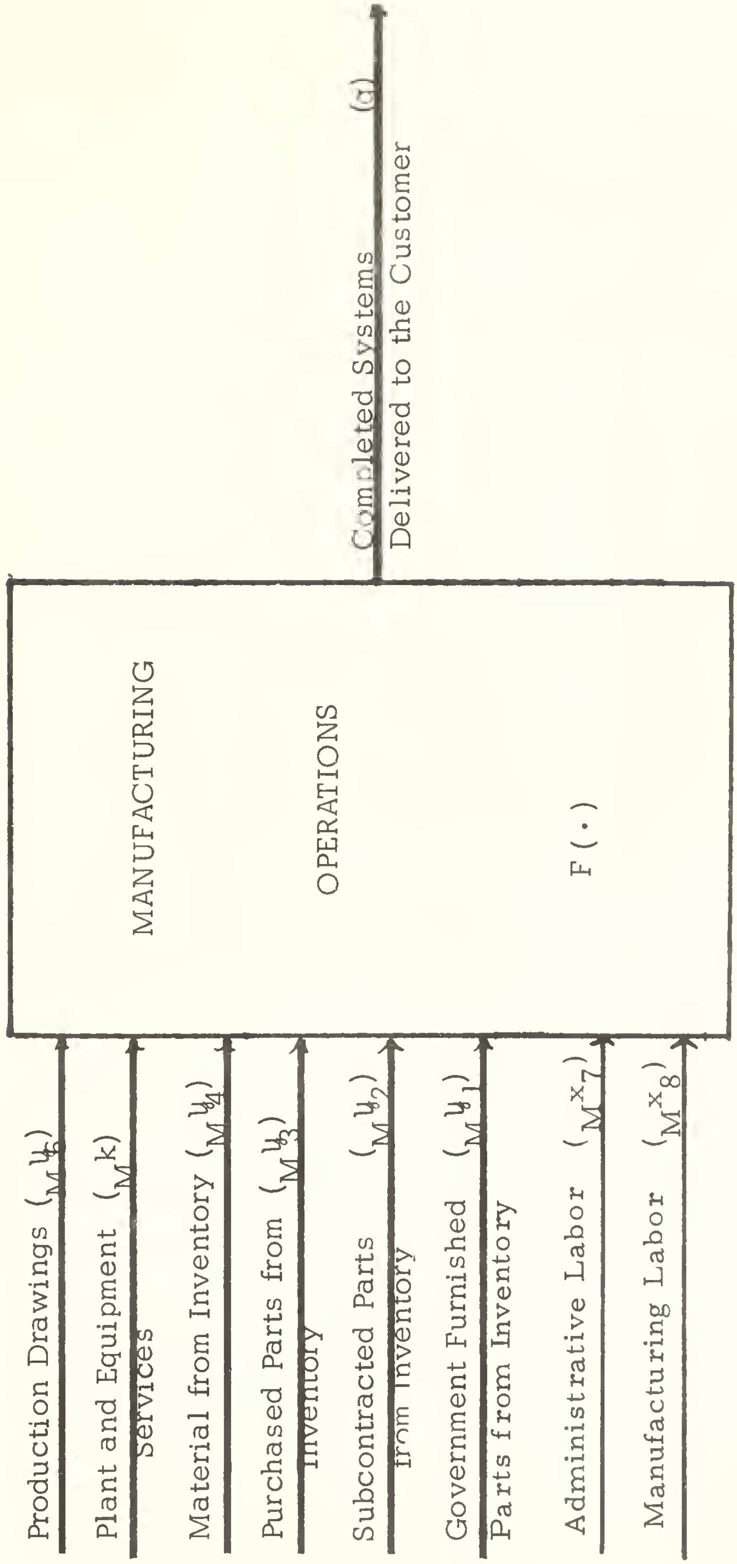


Figure II-4

Schematic of the Manufacturing Submodel

where

(1) $[\ ]$ denotes a vector

(2) $c = 1, 2, \cdots, C$

(3) $t \quad 1, 2, \cdots, T$

(4) $s = 1, 2, \cdots, S$

(5) M represents the use of an input in manufacturing operations

In addition to the above discussion, it is convenient to include at this point a discussion of the intermal to the firm balance aspects of production drawings. These are supplied by research and development for use by manufacturing. Thus, for the purpose of the model, production drawings are an input to production engineering. Production engineering is considered part of the manufacturing operations. Internal consistency dictates that the quantity supplied should not be exceed by that used. Thus, symbolically

$$R^{\psi}6 \geq M^{\psi}6$$

and with all time, contract and state-of-nature indices, it is

$$cR^{\psi}6ts \geq cM^{\psi}6ts$$

where

$c = 1, 2, \cdots, C$

$t = 1, 2, \cdots, T$

$s = 1, 2, \cdots, S$

R = research and development

T = test and evaluation

Finally, with respect to this submodel, the corporate management chooses the quantity of each input and the output in each time period, on each contract, and in each state-of-nature subject to the technological restraints of the manufacturing process itself.

E. The Commerical Sales Submodel

As indicated earlier, the contractor is assumed to have an ongoing commercial sales activity. For simplicity it is assumed that it is a pure manufacturing operation. As such, it has the same modeling form as the manufacturing submodel discussed in the last section with one exception. As a pure manufacturing operation, the production drawings are assumed already "within" the operations so that variable is omitted here. Otherwise it is so like Section II, D, only the final equations are stated here. The completed submodel is

$$F_{\theta}([{}_{\theta}q_{ts}]; [{}_{\theta M}k_{ts}], [{}_{\theta M}\psi_{4ts}], [{}_{\theta M}\psi_{3ts}], [{}_{\theta M}\psi_{2ts}]$$

$$[{}_{\theta M}\psi_{1ts}], [{}_{\theta M}x_{7ts}], [{}_{\theta M}x_{8ts}]) = 0$$

where

(1) [ ] denotes a vector

(2) $\theta$ denotes commercial sales

(3) $t = 1, 2, \cdots, T$

(4) $s = 1, 2, \cdots, S$

(5) M represents use of an input in manufacturing operations.

Finally, with respect to this submodel the corporate management chooses the quantity of each input and the output in each time period, and each state-of-nature subject to the technological restraints of the manufacturing process itself.

F. The Warehouse-Inventory Operations Submodel

As indicated in Chapter One the defense contractor modeled here is assumed to have a central warehouse-inventory operations system. This section contains the exposition of the structure of the model of that activity.

In general the warehouse-inventory operations are the operations whereby material, purchased parts, subcontracted parts, and government furnished parts are received, inspected, stored and issued for use by the rest of the firm's operations. To perform these activities the operations use warehouses, material handling equipment, inspectors, administrative people, warehousemen and the like. A schematic is shown as Figure II-5.

As shown on the schematic the warehouse-inventory operations receive, store, and issue on demand material ($x_3$, $\psi_4$), purchased parts ($x_4 \psi_3$), subcontracted parts ($x_5$, $\psi_2$) and government furnished parts ($x_6$, $\psi_1$). This operation is done by using plant and equipment services ($_w k$), administrative labor ($_w x_7$) and manufacturing labor ($_w x_8$). For each of exposition the discussion first focuses on warehouse operations then inventory operations.

For each type of item stored the space utilized must not exceed the space available. Assume that there is a relationship of space utilized by a given unit of a particular item stored to the quantity stored. Formally then, if $\bar{x}$ is the generic representation of the quantity in the warehouse, then $g(\bar{x})$ is the space utilized. Correspondingly, the space available is assumed to be a known relationship of plant and equipment services allocated to warehousing operations. Formally, $h(_w k)$ represents the total warehouse space available. It is assumed that $g(\bar{x})$ and $h(_w k)$ are continuous, have continuous second derivatives and that the first derivative is positive and the second negative. Overall, then, the space constraint is

$$g(\bar{x}_{3ts}) + g(\bar{x}_{4ts}) + g(\bar{x}_{5ts}) + g(\bar{x}_{6ts}) \leq h(_w k_{ts})$$

Note that the space utilized function is item specific.

In addition to the warehouse space constraint there is a constraint due to the capability of the workforce with its material handling equipment to withdraw and receive items. It is assumed that the overall capability to store and withdraw is a function of the labor (administrative and manufacturing) and plant and equipment services used.

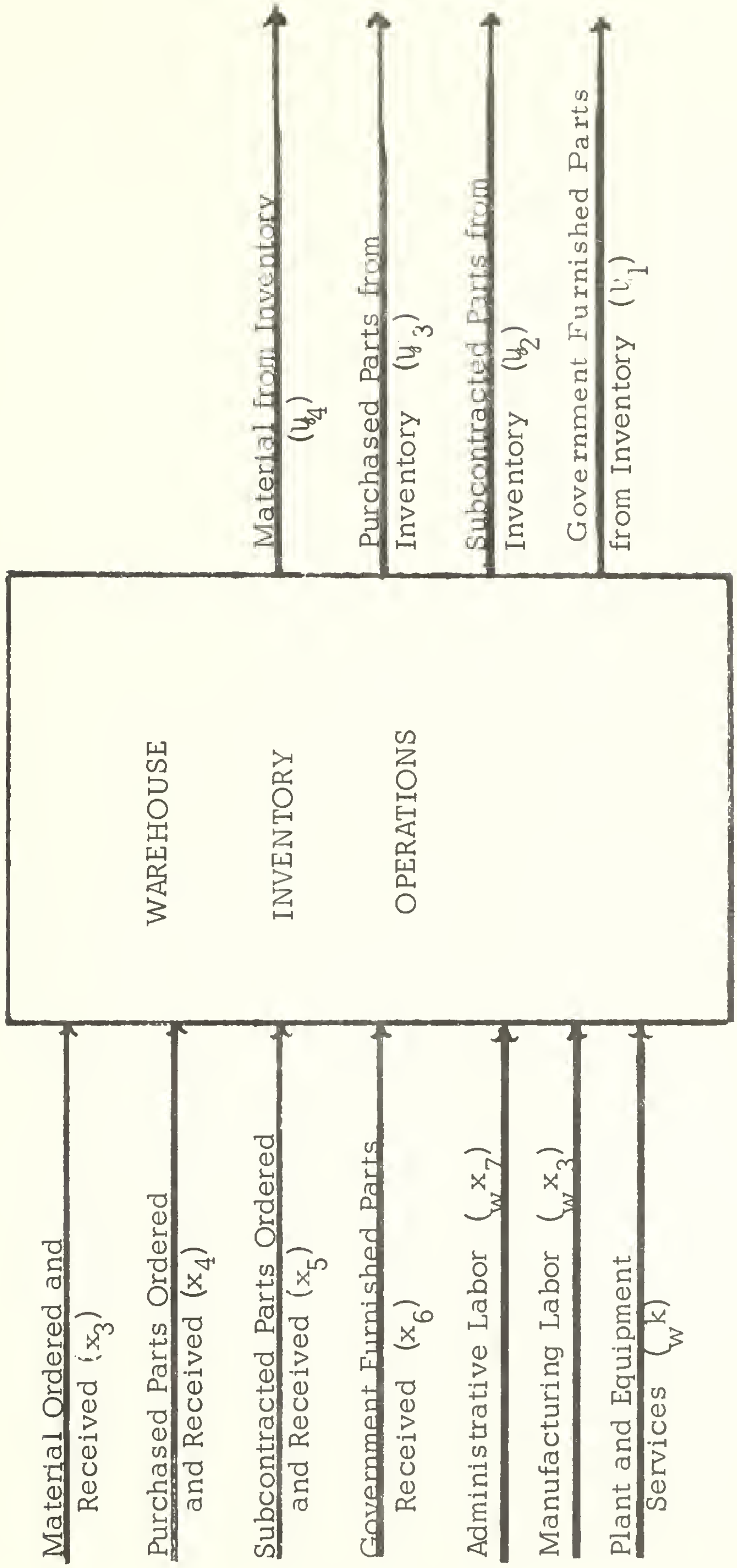


Figure II-5

Schematic of the Warehouse-Inventory Submodel

Formally $f({}_w x_7, {}_w x_8, {}_w k)$ represents this function. It is assumed that it exhibits continuous first and second derivatives, positive first derivatives, negative second "pure" derivatives and the second cross derivatives for each pair of variables are equal $\left(\text{e.g.}, \frac{\partial^2 f}{\partial_x x_7 \partial_w x_8} = \frac{\partial^2 f}{\partial_w x_8 \partial_w x_7}\right)$. It is assumed that the "time utilized in storing and withdrawing items is a function of the specific item involved. Thus, formally, the generic case is i(x) which is assumed to exhibit the same mathematical properties as the g(•) function discussed above. Overall, then, the 'time-utilization' constraint is

$$i_{x_3}(x_{3ts}) + i_{x_4}(x_{4ts}) + i_{x_5}({}_{5ts}) + 1_{x_6}(x_{6ts}) + i_{y}(y_{1ts}) + i_{y_2}(y_{2ts}) +$$

$$i_{y_3}(y_{3ts}) + i_{y_4}(y_{4ts}) = f({}_w x_{7ts}, {}_w x_{8ts}, {}_x k_{ts})$$

Note that the "time utilization" functions are item involved specific.

The inventory itself is governed by the equation that says the amount in storage at the beginning of a period equals the amount in storage at the beginning of the last time period plus any additions (receipts) minus any withdrawals. If a bar over the input letter designator for an item stored represents the stock level and all other variables are flows, then formally

$$\bar{x}_{3t} = \bar{x}_{3t-1} + x_{3t-1} - y_{4t-1} \qquad \text{(material)}$$

$$\bar{x}_{4t} = \bar{x}_{4t-1} + x_{4t-1} - y_{3t-1} \qquad \text{(purchased parts)}$$

$$\bar{x}_{5t} = \bar{x}_{5t-1} + x_{5t-1} - y_{2t-1} \qquad \text{(subcontracted parts)}$$

$$\bar{x}_{6t} = \bar{x}_{6t-1} + x_{6t-1} - y_{1t-1} \qquad \text{(government furnished parts)}$$

and the stock variable $(\bar{x}_3, \bar{x}_4, \bar{x}_5, \bar{x}_6)$ must be non-negative as must be the flow variables $(x_3, x_4, x_5, x_6, y_4, y_3, y_2, y_1)$. Using material as an example, a period-by-period representation is

$$\bar{x}_{30} \equiv \bar{\bar{x}}_{30} \qquad \text{(the initial stock level)}$$

$$\bar{x}_{31} = \bar{\bar{x}}_{30} + x_{30} - y_{40}$$

$$\bar{x}_{32} = \left(\bar{\bar{x}}_{30} + x_{30} - y_{40}\right) + x_{31} - y_{41} = \bar{\bar{x}}_{30} + \sum_{t=0}^{1} \left(x_{3t} - y_{4t}\right)$$

or more generally

$$\bar{x}_{3t} = \bar{\bar{x}}_{30} = \sum_{t=c}^{t-1} \left(x_{3t} - y_{4t}\right)$$

and similarly for the others

$$\bar{x}_{4t} = \bar{\bar{x}}_{40} + \sum_{t=0}^{t-1} \left(x_{4t} - y_{3t}\right)$$

$$\bar{x}_{5t} = \bar{\bar{x}}_{50} + \sum_{t=0}^{t-0} \left(x_{5t} - y_{2t}\right)$$

$$\bar{x}_{6t} = \bar{\bar{x}}_{60} + \sum_{t=0}^{t-1} \left(x_{6t} - y_{1t}\right)$$

In addition to these equations, the output of this centralized operation, the iterms issued, is demanded or issued to a variety of other activities. Thus, for material in time period t, this balance condition is

$$\underbrace{y_{4t}}_{\text{quantity supplied}} \geqq \underbrace{\sum_{c=1}^{C} \left({}_{cR}y_{4t} + {}_{cT}y_{4T} + {}_{cM}y_{4T}\right) + {}_{\theta}y_{4t}}_{\text{quantity demanded}}$$

where it is understood that all terms may not be applicable in each instance. For specifity with respect to contract-activity existence, the set of inequations shown in Table II-1 replaces the above inequation. The state-of-nature (alternative future) aspect is again introduced as an additional index. Note that the inequations shown in Table II-1 are for a specific state-of-nature and thus there are s=1, 2, ..., S such tables, one for each state-of-nature. Also there is one such table for material (1=4), purchased parts (i=3), subcontracted parts (i=2), and government furnished parts (i-1), with the understanding that for government furnished parts ${}_{\theta}y_{its}$ does not appear.

## TABLE II-1

## TIME PHASED INVENTORY BALANCE INEQUATIONS

$i = 1, 2, 3, 4$ $\qquad$ $s = 1, 2, \ldots, S$ $\qquad$ $i = 1, \; {}_\theta y_{1ts} \equiv 0$

| | |
|---|---|
| $0 \leq t \leq t_1$ | $y_{its} \geq \sum_{c=1}^{2,5} {}_cR^y_{its} + \sum_{c=2}^{3} {}_cT^y_{its} + {}_4M^y_{its} + {}_\theta y_{its}$ |
| $t_1 \leq \quad \leq t_2$ | $y_{its} \geq \sum_{c=1,5} {}_cR^y_{its} + \sum_{c=2}^{3} {}_cT^y_{its} + {}_4M^y_{its} + {}_\theta y_{its}$ |
| $t_2 \leq t \leq t_3$ | $y_{its} \geq \sum_{c=1,5} {}_cR^y_{its} + \sum_{c=1}^{3,13} {}_cT^y_{its} + {}_4M^y_{its} + {}_\theta y_{its}$ |
| $t_3 \leq t \leq t_4$ | $y_{its} \geq \sum_{c=1,5} {}_cR^y_{its} + \sum_{c=1}^{3,13} {}_cT^y_{its} + \sum_{c=3}^{4} {}_cM^y_{its} + {}_\theta y_{its}$ |
| $t_4 \leq t \leq t_5$ | $y_{its} \geq \sum_{c=5,6} {}_cR^y_{its} + \sum_{c=1}^{3,13} {}_cT^y_{its} + \sum_{c=3}^{4} {}_cM^y_{its} + {}_\theta y_{its}$ |
| $t_5 \leq t \leq t_6$ | $y_{its} \geq \sum_{c=5}^{6} {}_cR^u_{its} + \sum_{c=1}^{2,13} {}_cT^y_{its} + \sum_{c=3}^{4} {}_cM^y_{its} + {}_\theta y_{its}$ |
| $t_6 \leq t \leq t_7$ | $y_{its} \geq {}_6R^y_{its} + \sum_{c=1}^{2,13} {}_cT^y_{its} + \sum_{c=2}^{4} {}_cM^y_{its} + {}_\theta y_{its}$ |
| $t_7 \leq t \leq t_8$ | $y_{its} \geq {}_6R^y_{its} + \sum_{c=1}^{2,13} {}_cT^y_{its} + \sum_{c=1}^{4} {}_cM^y_{its} + {}_\theta y_{its}$ |
| $t_8 \leq t \leq t_9$ | $y_{its} \geq {}_6R^y_{its} + \sum_{c=1,13} {}_cT^y_{its} + \sum_{c=1}^{4} {}_cM^y_{its} + {}_\theta y_{its}$ |
| $t_9 \leq t \leq t_{10}$ | $y_{its} \geq {}_6R^y_{its} + {}_{13}T^y_{its} + \sum_{c=1}^{4} {}_cM^y_{its} + {}_\theta y_{its}$ |
| $t_{10} \leq t \leq t_{11}$ | $y_{its} \geq {}_6R^y_{its} + \sum_{c=6,13} {}_cT^y_{its} + \sum_{c=1}^{3} {}_cM^y_{its} + {}_\theta y_{its}$ |

TABLE II-1 (cont'd)

| | |
|---|---|
| $t_{11} \leqq t \leqq t_{12}$ | $y_{its} \geqq {}_{6}R^{y}{}_{its} + \sum_{c=6,13} {}_{c}T^{y}{}_{its} + \sum_{c=1}^{3} {}_{c}M^{y}{}_{its} + {}_{\theta}{}^{y}{}_{its}$ |
| $t_{12} \leqq t \leqq t_{13}$ | $y_{its} \geqq \quad + \sum_{c=6,13} {}_{c}T^{y}{}_{its} + \sum_{c=1}^{3} {}_{c}M^{y}{}_{its} + {}_{\theta}{}^{y}{}_{its}$ |
| $t_{13} \leqq t \leqq t_{14}$ | $y_{its} \geqq {}_{7}R^{y}{}_{its} + \sum_{c=6,13} {}_{c}T^{y}{}_{its} + \sum_{c=1}^{3} {}_{c}M^{y}{}_{its} + {}_{\theta}{}^{y}{}_{ts}$ |
| $t_{14} \leqq t \leqq t_{15}$ | $y_{its} \geqq {}_{7}R^{y}{}_{its} + \sum_{c=6,13} {}_{c}T^{y}{}_{its} + \sum_{c=1}^{6} {}_{c}M^{y}{}_{its} + \theta^{y}{}_{its}$ |
| $t_{15} \leqq t \leqq t_{16}$ | $y_{its} \geqq {}_{7}R^{y}{}_{its} + \sum_{c=6,13} {}_{c}T^{y}{}_{its} + \sum_{c=1}^{2,6} {}_{c}M^{y}{}_{its} + \theta^{y}{}_{its}$ |
| $t_{16} \leqq t \leqq t_{17}$ | $y_{its} \geqq {}_{7}R^{y}{}_{its} + {}_{6}T^{y}{}_{its} + \sum_{c=2,6} {}_{c}M^{y}{}_{its} + \theta^{y}{}_{its}$ |
| $t_{17} \leqq t \leqq t_{18}$ | $y_{its} \geqq \sum_{c=7,8} {}_{c}R^{y}{}_{its} + {}_{6}T^{y}{}_{its} + \sum_{c=2,6} {}_{c}M^{y}{}_{its} + \theta^{y}{}_{its}$ |
| $t_{18} \leqq t \leqq t_{19}$ | $y_{its} \geqq \sum_{c=7,8} {}_{c}R^{y}{}_{its} + \sum_{c=6,7} {}_{c}T^{y}{}_{its} + {}_{6}M^{y}{}_{its} + \theta^{y}{}_{its}$ |
| $t_{19} \leqq t \leqq t_{20}$ | $y_{its} \geqq \sum_{c=7,8} {}_{c}R^{y}{}_{its} + {}_{7}T^{y}{}_{its} + {}_{6}M^{y}{}_{its} + \theta^{y}{}_{its}$ |
| $t_{20} \leqq t \leqq t_{21}$ | $y_{its} \geqq {}_{8}R^{y}{}_{its} + \sum_{c=7,14} {}_{c}T^{y}{}_{its} + {}_{6}M^{y}{}_{its} + \theta^{y}{}_{its}$ |
| $t_{21} \leqq t \leqq t_{22}$ | $y_{its} \geqq {}_{8}R^{y}{}_{its} + \sum_{c=7,14} {}_{c}T^{y}{}_{its} + \sum_{c=6}^{7} {}_{c}M^{y}{}_{its} + \theta^{y}{}_{its}$ |

TABLE II-1 (cont'd)

| | |
|---|---|
| $t_{22} \leqq t \leqq t_{23}$ | $y_{its} \geqq \sum_{c=8}^{9} cR^{y}_{its} + \sum_{c=7,14} cT^{y}_{its} + \sum_{c=6} cM^{y}_{its} + \theta^{y}_{its}$ |
| $t_{23} \leqq t \leqq t_{24}$ | $y_{its} \geqq \sum_{c=8}^{9} cR^{y}_{its} + 14T^{y}_{its} + \sum_{c=6}^{7} cM^{y}_{its} + \theta^{y}_{its}$ |
| $t_{24} \leqq t \leqq t_{25}$ | $y_{its} \geqq \sum_{c=8}^{9} cR^{y}_{its} + \sum_{c=9,14} cT^{y}_{its} + \sum_{c=6}^{7} cM^{y}_{its} + \theta^{y}_{its}$ |
| $t_{25} \leqq t \leqq t_{26}$ | $y_{its} \geqq \sum_{c=8}^{9} cR^{y}_{its} + \sum_{c-9,14} cT^{y}_{its} + 7M^{y}_{its} + \theta^{y}_{its}$ |
| $t_{26} \leqq t \leqq t_{27}$ | $y_{its} \geqq 8R^{y}_{its} + 9T^{y}_{its} + \sum_{c=7,9} cM^{y}_{its} + \theta^{y}_{its}$ |
| $t_{27} \leqq t \leqq t_{28}$ | $y_{its} \geqq \qquad + 9T^{y}_{its} + \sum_{c=7,9} cM^{y}_{its} + \theta^{y}_{its}$ |
| $t_{28} \leqq t \leqq t_{29}$ | $y_{its} \geqq 10R^{y}_{its} + 9T^{y}_{its} + \sum_{c=7,9} cM^{y}_{its} + \theta^{y}_{its}$ |
| $t_{29} \leqq t \leqq t_{30}$ | $y_{its} \geqq 10R^{y}_{its} + \qquad + \sum_{c=7,9} cM^{y}_{its} + \theta^{y}_{its}$ |
| $t_{30} \leqq t \leqq t_{31}$ | $y_{its} \geqq 10R^{y}_{its} + \qquad + 9M^{y}_{its} + \theta^{y}_{its}$ |
| $t_{31} \leqq t \leqq t_{32}$ | $y_{its} \geqq 10R^{y}_{its} + 10T^{y}_{its} + 9M^{y}_{its} + \theta^{y}_{its}$ |
| $t_{32} \leqq t \leqq t_{33}$ | $y_{its} \geqq \qquad + 10T^{y}_{its} + 9M^{y}_{its} + \theta^{y}_{its}$ |

TABLE II-1 (cont'd)

$$t_{33} \leqq t \leqq t_{34} \qquad y_{its} \geqq {}_{11}R^{y}{}_{its} + {}_{10}T^{y}{}_{its} + {}_{9}M^{y}{}_{its} + \theta^{y}{}_{its}$$

$$t_{34} \leqq t \leqq t_{35} \qquad y_{its} \geqq {}_{11}R^{y}{}_{its} + {}_{10}T^{y}{}_{its} + \sum_{c=9}^{10} {}_{c}M^{y}{}_{its} + \theta^{y}{}_{its}$$

$$t_{35} \leqq t \leqq t_{36} \qquad y_{its} \geqq \sum_{c=11}^{12} {}_{c}R^{y}{}_{its} + {}_{10}T^{y}{}_{its} + \sum_{c\ 9}^{10} {}_{c}M^{y}{}_{its} + \theta^{y}{}_{its}$$

$$t_{36} \leqq t \leqq T \qquad y_{its} \geqq \sum_{c=11}^{12} {}_{c}R^{y}{}_{its} + \sum_{c=10}^{11} {}_{c}T^{y}{}_{its} + \sum_{c=9}^{10} {}_{c}M^{y}{}_{its} + \theta^{y}{}_{its}$$

Finally, with respect to this submodel, the corporate management chooses the quantity of material, purchased parts, subcontracted parts to purchase and receive in each time period and in each state-of-nature. The quantity of government furnished parts is not perceived within the control of the corporate management as it is perceived as a government decision variable by the corporate management. Since delivery of such parts supplied by the government are not without scheduling difficulties, the various contingencies are part of the state-of-nature construction. The outputs of material, purchased parts, subcontracted parts, and government furnished parts is chosen by the corporate management. Finally, the quality of administrative labor, manufacturing labor and plant and equipment services allocated to warehouse-inventory operation is chosen for each period and each state-of-nature.

G. The Plant and Equipment Sub model

As discussed in the previous submodels, plant and equipment services are used in all phases of government contracts, in commericial product manufacturing as well as the warehouse-inventory operations. In this submodel the discussion focuses on the acquisition of new plant and equipment, both privately by the contractor, as well as via government furnished real property. Overall such acquisition decisions are a part of management's total decision problem and as such considers a capital labor trade off as well as what costs are reimbursable under a government contract. It also focuses on physical depreciation and the allocation of plant and equipment to the various operations. Plant and equipment will be measured in this paper in terms of the services rendered by plant and equipment (e.g., machine hours).

At any moment of time there is a stock of available services (measured in, for example, machine hours) of which some ($k_{1t}$) is supplied by the government. The total available is

$$k_t = k_{1t} + k_{2t}$$

Also at any moment of time there is a usage of plant and equipment services in each operation. The total usage is then

$$_u k_t = \sum_c {}_cR^k{}_t + \sum_c {}_cT^k{}_t + \sum_c {}_cM^k{}_t + {}_\theta{}^k{}_t + {}_w{}^k{}_t$$

where for ease of reading it is noted that

| | | |
|---|---|---|
| $_u{}^k{}_t$ | $\equiv$ | total plant and equipment needed for current operation |
| $_cR^k{}_t$ | $\equiv$ | total plant and equipment needed for current research and development operations on contract c |
| $_cT^k{}_t$ | $\equiv$ | total plant and equipment needed for current test and evaluation operations on contract c |
| $_cM^k{}_t$ | $\equiv$ | total plant and equipment needed for current manufacturing operations on contract c |
| $_\theta{}^k{}_t$ | $\equiv$ | total plant and equipment needed for commercial manufacturing operations |
| $_w{}^k{}_t$ | $\equiv$ | total plant and equipment needed for current operations of the warehouse-inventory system |

The summation over c should be interpreted as over the existing contract operations relevant to that date. System consistency for the contractor require usage be less than that available

$$k_t \geq {}_u{}^k{}_6$$

or

$$k_{1t} + k_{2t} \geq \sum_c {}_cR^k{}_t + \sum_c {}_cT^k{}_t + \sum_c {}_cM^k{}_t + {}_\theta{}^k{}_t + {}_w{}^k{}_t$$

Table II-2 shows the details of the time phasing of this inequation for each state-of-nature.

## TABLE II-2

## TIME PHASED PLANT AND EQUIPMENT BALANCE INEQUATIONS

| | |
|---|---|
| $0 \leqq t \leqq t$ | $k_{1ts} + k_{2ts} \geqq \sum_{c=1}^{2,5} {}_{c}R^{k}{}_{ts} + \sum_{c=2}^{3} {}_{c}T^{k}{}_{ts} + {}_{4}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_1 \leqq t \leqq t_2$ | $k_{1ts} + k_{2ts} \geqq \sum_{c=1,5} {}_{c}R^{k}{}_{ts} + \sum_{c=2}^{3} {}_{c}T^{k}{}_{ts} + {}_{4}M^{1}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_2 \leqq t \leqq t_3$ | $k_{1ts} + k_{2ts} \geqq \sum_{c=1,5} {}_{c}R^{k}{}_{ts} + \sum_{c=1}^{3,13} {}_{c}T^{k}{}_{ts} + {}_{4}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_3 \leqq t \leqq t_4$ | $k_{1ts} + k_{2ts} \geqq \sum_{c=1,5} {}_{c}R^{k}{}_{ts} + \sum_{c=1}^{3,13} {}_{c}T^{k}{}_{ts} + \sum_{c=3}^{4} {}_{c}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_4 \leqq t \leqq t_5$ | $k_{1ts} + k_{2ts} \geqq \sum_{c=5}^{6} {}_{c}R^{k}{}_{ts} + \sum_{c=1}^{3,13} {}_{c}T^{k}{}_{ts} + \sum_{c=3}^{4} {}_{c}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_5 \leqq t \leqq t_6$ | $k_{1ts} + k_{2ts} \geqq \sum_{c=5}^{6} {}_{c}R^{k}{}_{ts} + \sum_{c=1}^{2,13} {}_{c}T^{k}{}_{ts} + \sum_{c=3}^{4} {}_{c}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_6 \leqq t \leqq t_7$ | $k_{1ts} + k_{2ts} \geqq {}_{6}R^{k}{}_{ts} + \sum_{c=1}^{2,13} {}_{c}T^{k}{}_{ts} + \sum_{c=2}^{4} {}_{c}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_7 \leqq t \leqq t_8$ | $k_{1ts} + k_{2ts} \geqq {}_{6}R^{k}{}_{ts} + \sum_{c=1}^{2,13} {}_{c}T^{k}{}_{ts} + \sum_{c=1}^{4} {}_{c}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_8 \leqq t \leqq t_9$ | $k_{1ts} + k_{2ts} \geqq {}_{6}R^{k}{}_{ts} + \sum_{c=1,13} {}_{c}M^{k}{}_{ts} + \sum_{c=1}^{4} {}_{c}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_9 \leqq t \leqq t_{10}$ | $k_{1ts} + k_{2ts} \geqq {}_{6}R^{k}{}_{ts} + {}_{13}T^{k}{}_{ts} + \sum_{c=1}^{4} {}_{c}M^{k}{}_{ys} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_{10} \leqq t \leqq t_{11}$ | $k_{1ts} + k_{2ts} \geqq {}_{6}R^{k}{}_{ts} + {}_{13}T^{k}{}_{ts} + \sum_{c=1}^{3} {}_{c}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |
| $t_{11} \leqq t \leqq t_{12}$ | $k_{1ts} + k_{2ts} \geqq {}_{6}R^{k}{}_{ts} + \sum_{c=6,13} {}_{c}T^{k}{}_{ts} + \sum_{c=1}^{3} {}_{c}M^{k}{}_{ts} + \theta^{k}{}_{ts} + w^{k}{}_{ts}$ |

TABLE II -2 (cont'd)

$$t_{12} \leqq t \leqq t_{13} \qquad k_{1ts} + k_{2ts} \geqq \quad + \sum_{c=6,13} {}_cT^k{}_{ts} + \sum_{c=1}^{3} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{13} \leqq t \leqq t_{14} \qquad k_{1ts} + k_{2ts} \geqq {}_7R^k{}_{ts} + \sum_{c=6,13} {}_cT^k{}_{ts} + \sum_{c=1}^{3} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{14} \leqq t \leqq t_{15} \qquad k_{1ts} + k_{2ts} \geqq {}_7R^k{}_{ts} + \sum_{c=6,13} {}_cT^k{}_{ts} + \sum_{c=1}^{2} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{15} \leqq t \leqq t_{16} \qquad k_{1ts} + k2ts \geqq {}_7R^k{}_{ts} + \sum_{c=6,13} {}_cT^k{}_{ts} + \sum_{c=1}^{2,6} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{16} \leqq t \leqq t_{17} \qquad k_{1ts} + k_{2ts} \geqq {}_7R^k{}_{ts} + {}_6T^k{}_{ts} + \sum_{c=2,6} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{17} \leqq t \leqq t_{18} \qquad k_{1ts} + k_{2ts} \geqq \sum_{c=7}^{8} {}_cR^k{}_{ts} + {}_6T^k{}_{ts} + \sum_{c=2,6} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{18} \leqq t \leqq t_{19} \qquad k_{1ts} + k_{2ts} \geqq \sum_{c=7}^{8} {}_cR^k{}_{ts} + \sum_{c=6}^{7} {}_cT^k{}_{ts} + {}_6M^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{19} \leqq t \leqq t_{20} \qquad k_{1ts} + k_{2ts} \geqq \sum_{c=7}^{8} {}_cR^k{}_{ts} + {}_7T^k{}_{ts} + {}_6M^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{20} \leqq t \leqq t_{21} \qquad k_{1ts} + k_{2ts} \geqq {}_8R^k{}_{ts} + \sum_{c=7,14} {}_cT^k{}_{ts} + {}_6M^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{21} \leqq t \leqq t_{22} \qquad k_{1ts} + k_{2ts} \geqq {}_8R^k{}_{ts} + \sum_{c=7,14} {}_cT^k{}_{ts} + \sum_{c=6}^{7} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{22} \leqq t \leqq t_{23} \qquad k_{1ts} + k_{2ts} \geqq \sum_{c=8}^{9} {}_cR^k{}_{ts} + \sum_{c=7,14} {}_cT^k{}_{ts} + \sum_{c=6}^{7} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

$$t_{23} \leqq t \leqq t_{24} \qquad k_{1ts} + k_{2ts} \geqq \sum_{c=8}^{9} {}_cR^k{}_{ts} + {}_{14}T^k{}_{ts} + \sum_{c=6}^{7} {}_cM^k{}_{ts} + \theta^k{}_{ts} + w^k{}_{ts}$$

TABLE II-2 (cont'd)

| | |
|---|---|
| $t_{24} \leq t \leq t_{25}$ | $k_{1ts} + k_{2ts} \geq \sum_{c=8}^{9} cR^{k}_{ts} + \sum_{c=9,14} cT^{k}_{ts} + \sum_{c=6}^{7} cM^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{25} \leq t \leq t_{26}$ | $k_{1ts} + k_{2ts} \geq \sum_{c=8}^{9} cR^{k}_{ts} + \sum_{c=9,14} cT^{k}_{ts} + 7M^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{26} \leq t \leq t_{27}$ | $k_{1ts} + k_{2ts} \geq 8R^{k}_{ts} + 9T^{k}_{ts} + \sum_{c=7,9} cM^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{27} \leq t \leq t_{28}$ | $k_{1ts} + k_{2ts} \geq \qquad + 9T^{k}_{ts} + \sum_{c=7,9} cM^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{28} \leq t \leq t_{29}$ | $k_{1ts} + k_{2ts} \geq 10R^{k}_{ts} + 9T^{k}_{ts} + \sum_{c=7,9} cM^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{29} \leq t \leq t_{30}$ | $k_{1ts} + k_{2ts} \geq 10R^{k}_{ts} + \qquad + {}_{c=7,9} cM^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{30} \leq t \leq t_{31}$ | $k_{1ts} + k_{2ts} \geq 10R^{k}_{ts} + \qquad + 9M^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{31} \leq t \leq t_{32}$ | $k_{1ts} + k_{2ts} \geq 10R^{k}_{ts} + 10T^{k}_{ts} + 9M^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{32} \leq t \leq t_{33}$ | $k_{1ts} + k_{2ts} \geq \qquad + 10T^{k}_{ts} + 9M^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{33} \leq t \leq t_{34}$ | $k_{1ts} + k_{2ts} \geq 11R^{k}_{ts} + 10T^{k}_{ts} + 9M^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{34} \leq t \leq t_{35}$ | $k_{1ts} + k_{2ts} \geq 11R^{k}_{ts} + 10T^{k}_{ts} + \sum_{c=9}^{10} cM^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{35} \leq t \leq t_{36}$ | $k_{1ts} + k_{2ts} \geq \sum_{c+11}^{12} cR^{k}_{ts} + 10T^{k}_{ts} + \sum_{c=9}^{10} cM^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |
| $t_{36} \leq t \leq T$ | $k_{1ts} + k_{2ts} \geq \sum_{c=11}^{12} cR^{k}_{ts} + \sum_{c=10}^{11} cT^{k}_{ts} + \sum_{c=9}^{10} cM^{k}_{ts} + \theta^{k}_{ts} + w^{k}_{ts}$ |

In addition to this set of inequartions describing the allocation of existing plant and equipment, there is also the phenomenon of investment in plant and equipment by the contractor as well as by the government. The government's additions to plant and equipment is assumed to be perceived by the contractor as beyond the contractor's control. Thus the change in government supplied plant and equipment ($\dot{k}_{1t}$) is assumed exogenous to the firm. It is thus a major candidate for study as to its effect on contractor conduct. The contractor's own investment ($\dot{k}_{2t}$) is a choice variable for the contractor. Note that the use of a dot over the variable is unconventional notation in discrete time models; however, it reduces the notational complexity, so is used here.

Depreciation is assumed to be a physical process of wear, tear, and accidental breakage. It is assumed that $\delta$ percent of the existing stock of plant and equipment whether owned by the government or the contractor "evaporates" in each time period. For simplicity, "todays" new investment does not begin to depreciate until tomorrow.

With this in mind and the idea that today's stock is yesterday's plus investment minus depreciation, the basic equation is written as

$$k_{1t} + k_{2t} = k_{1t-1} + k_{2t-1} + \dot{k}_{2t-1} + \dot{k}_{1t-1} - \delta(k_{1t-1} + k_{2t-1})$$

or

$$k_{1t} + k_{2t} = (1-\delta)(k_{1t-1} + k_{2t-1}) + \dot{k}_{1t-1} + \dot{k}_{2t-1}$$

This difference equation detailed over time is

$$k_{10} + k_{20} = \bar{\bar{k}}_{10} + \bar{\bar{k}}_{20}$$

$$k_{11} + k_{21} = (1-\delta)\,\bar{\bar{k}}_{10} + (1-\delta)\bar{\bar{k}}_{20} + \dot{k}_{10} + \dot{k}_{20}$$

$$k_{12} + k_{22} = (1-\delta)^{2}\bar{\bar{k}}_{10} + (1-\delta)^{2}\bar{\bar{k}}_{20} + (1-\delta)\dot{k}_{10} + (1-\delta)\dot{k}_{20} + \dot{k}_{11} + \dot{k}_{21}$$

$$\vdots$$

$$k_{1t} + k_{2t} = (1-\delta)^{t}\bar{\bar{k}}_{10} + (1-\delta)^{t}\bar{\bar{k}}_{20} + (1-\delta)^{t-1}\dot{k}_{10} + (1-\delta)^{t-1}\dot{k}_{20}$$

$$\cdots + (1-\delta)\dot{k}_{1t-2} + (1-\delta)\dot{k}_{2t-2} + \dot{k}_{1t-1} + \dot{k}_{2t-1}$$

$$= (1-\delta)^{t}\bar{\bar{k}}_{10} + \sum_{j=1}^{t}(1-\delta)^{t-j}\dot{k}_{1j-1} + (1-\delta)^{t}\bar{\bar{k}}_{20} + \sum_{j=1}^{t}(1-\delta)^{t-j}\dot{k}_{2j-1}$$

Including the state-of-nature, the general expression is

$$k_{1ts} + k_{2ts} = (1-\delta)^t \bar{\bar{k}}_{10s} + \sum_{j=1}^{t} (1-\delta)^{t-j} \dot{k}_{1j-1s} + (1-\delta)^t \bar{\bar{k}}_{20s} + \sum_{j=1}^{t} (1-\delta)^{t-j} \dot{k}_{2j-1s}$$

Note that for simplicity the physical depreciation rate is assumed to be invariant with respect to time and state-of-nature. In future work usage and state-of-nature effects will be considered.

This submodel, then, in equation form is the above combined with Table II-2. The contractor chooses the quantity of new plant and equipment to purchase, and the allocation of the total existing stock to each contract's activities and commercial product production in each state-of-nature. The government provides its contribution to plant and equipment exogenously to the form.

## H. The Engineering Labor Submodel

As noted in the discussion of the operations oriented submodels, engineering labor is an input to both research and development and test and evaluation. In the former case only contractor personnel are involved while in the later case a mix of contractor and govenment personnel are involved. The discussion in this section first considers the usage side, then the source of labor side, and finally the necessary relationship between the two.

Usage in the research and development operation in time period t, on contract c, and in state-of-nature s is denoted by ${}_{cR}x_{1ts}$. Usage of engineering labor in the test and evaluation operations in time period t, on contract c and in state-of-nature s is denoted by ${}_{cT}x_{13ts}$. By summing over the appropriate contracts on a given date, total demand may be calculated. For convenience at this state of the discussion, this is denoted as

$$\sum_{c} {}_{cR}x_{1ts} \text{ and } \sum_{c} {}_{cT}x_{13ts}$$

The supply of contractor engineering labor is purchased from the labor market by the contractor in each time period and in each date-of-nature. This is denoted as $x_{1ts}$. The government does an analogous activity which is denoted as $x_{10ts}$.

The relationship of availability of labor and its usage is governed by the concept that total usage must be less than or equal to the total available. Let ${}_{T}x_{1ts}$ denote the quantity of contractor supplied engineering labor devoted to test and evaluation. Then the total supply is ${}_{T}x_{1ts} + x_{10ts}$ which is related to the usage by

$$ {}_{T}x_{1ts} + x_{10ts} = \sum_{c} {}_{cT}\,{}_{13ts}. $$

In addition, the same concept applies to research and development and the contractor supply of engineering labor. This is shown as

$$ x_{1ts} = {}_{T}x_{1ts} + \sum_{c} {}_{cR}x_{1ts} $$

It is clear that these two inequalities can be combined into an aggregate relationship. However, this could obscure the contractor's decisions with respect to the allocation of engineering labor between R and D and T and E. Since this allocation is of interest, the inequalities are kept separate. Table II- 3 contains the details on these inequalities as applicable by time period and contract.

Finally, the contractor chooses the amount of engineering labor to purchase in each time period and each state-of-nature. In addition, the contractor chooses the amount of contractor engineering labor to be used on each contract by R&D and T&E activities in each time period and each state-of-nature. To keep the complexity of the model within bounds, all internal labor transfer and training costs are considered negligible. The government's engineering labor is exogenously supplied to the contractor with the state-of-nature index representing that the quantity supplied is not known with certainty to the contractor.

TABLE II-3

TIME PHASED ENGINEERING LABOR BALANCE INEQUATIONS

$0 \leq t \leq t_1$

$$ {}_{T}x_{1ts} + x_{10ts} \geq \sum_{c=2}^{3} {}_{cT}x_{13ts} $$

$$ x_{1ts} \geq {}_{T}x_{1ts} + \sum_{c=1}^{2,5} {}_{cR}x_{1ts} $$

$t_1 \leq t \leq t_2$

$$ {}_{T}x_{1ts} + x_{10ts} \geq \sum_{c=2}^{3} {}_{cT}x_{13ts} $$

$$ x_{1ts} \geq {}_{T}x_{1ts} + \sum_{c=1,5} {}_{cR}x_{1ts} $$

$t_2 \leq t \leq t_3$

$$ {}_{T}x_{1ts} + x_{10ts} \geq \sum_{c=1}^{3,13} {}_{cT}x_{13ts} $$

$$ x_{1ts} \geq {}_{T}x_{1ts} + \sum_{c=1,5} {}_{cR}x_{1ts} $$

$t_3 \leq t \leq t_4$

$$ {}_{T}x_{1ts} + x_{10ts} \geq \sum_{c=1}^{3,13} {}_{cT}x_{13ts} $$

$$ x_{1ts} \geq {}_{T}x_{1ts} + \sum_{c=1,5} {}_{cR}x_{1ts} $$

$t_4 \leq t \leq t_5$

$$ {}_{T}x_{1ts} + x_{10ts} \geq \sum_{c=1}^{3,13} {}_{cT}x_{13ts} $$

$$ x_{1ts} \geq {}_{T}x_{1ts} + \sum_{c=5}^{6} {}_{cR}x_{1ts} $$

$t_5 \leq t \leq t_6$

$$ {}_{T}x_{1ts} + x_{10ts} \geq \sum_{c=1}^{2,13} {}_{cT}x_{13ts} $$

$$ x_{1ts} \geq {}_{T}x_{1ts} + \sum_{c=5}^{6} {}_{cR}x_{1ts} $$

TABLE II-3 (cont'd)

| | |
|---|---|
| $t_6 \leqq t \leqq t_7$ | ${}_{T}x_{1ts} + x_{10ts} \geqq \sum_{c+1}^{2,13} {}_{cT}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + {}_{6R}x_{1ts}$ |
| $t_7 \leqq t \leqq t_8$ | ${}_{T}x_{1ts} + x_{10ts} \geqq \sum_{c=1}^{2,13} {}_{cT}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + {}_{6R}x_{1ts}$ |
| $t_8 \leqq t \leqq t_9$ | ${}_{T}x_{1ts} + x_{10ts} \geqq \sum_{c=1,13} {}_{cT}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + {}_{6R}x_{1ts}$ |
| $t_9 \leqq t \leqq t_{10}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq {}_{13T}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + {}_{6R}x_{1ts}$ |
| $t_{10} \leqq t \leqq t_{11}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq {}_{13T}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + {}_{6R}x_{1ts}$ |
| $t_{11} \leqq t \leqq t_{12}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq \sum_{c=6,13} {}_{cT}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + {}_{6R}x_{1ts}$ |
| $t_{12} \leqq t \leqq t_{13}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq \sum_{c=6,13} {}_{cT}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts}$ |

TABLE II-3 (cont'd)

| | |
|---|---|
| $t_{14} \leqq t \leqq t_{15}$ | $T^x_{1ts} + x_{10ts} \geqq \sum_{c=6,13} {}_cT^x_{13ts}$ |
| | $x_{1ts} \geqq T^x_{1ts} + {}_7R^x_{1ts}$ |
| $t_{15} \leqq t \leqq t_{16}$ | $T^x_{1ts} + x_{10ts} \geqq \sum_{c=6,13} {}_cT^x_{13ts}$ |
| | $x_{1ts} \geqq T^x_{1ts} + {}_7R^x_{1ts}$ |
| $t_{16} \leqq t \leqq t_{17}$ | $T^x_{1ts} + x_{10ts} \geqq {}_6T^x_{13ts}$ |
| | $x_{1ts} \geqq T^x_{1ts} + {}_7R^x_{1ts}$ |
| $t_{17} \leqq t \leqq t_{18}$ | $T^x_{1ts} + x_{10ts} \geqq {}_6T^x_{13ts}$ |
| | $x_{1ts} \geqq T^x_{1ts} + \sum_{c=7}^{8} {}_cR^x_{1ts}$ |
| $t_{18} \leqq t \leqq t_{19}$ | $T^x_{1ts} + x_{10ts} \geqq \sum_{c=6}^{7} {}_cT^x_{13ts}$ |
| | $x_{1ts} \geqq T^x_{1ts} + \sum_{c=7}^{8} {}_cR^x_{1ts}$ |
| $t_{19} \leqq t \leqq t_{20}$ | $T^x_{1ts} + x_{10ts} \geqq {}_7T^x_{13ts}$ |
| | $x_{1ts} \geqq T^x_{1ts} + \sum_{c=7}^{8} {}_cR^x_{1ts}$ |
| $t_{20} \leqq t \leqq t_{21}$ | $T^x_{1ts} + x_{10ts} \geqq \sum_{c=7,14} {}_cT^x_{13ts}$ |
| | $x_{1ts} \geqq T^x_{1ts} + {}_8R^x_{1ts}$ |

TABLE II-3 (cont'd)

| | |
|---|---|
| $t_{21} \leqq t \leqq t_{22}$ | $T^{x}_{1ts} + x_{10ts} \geqq \sum_{c=7,14} cT^{x}_{13ts}$ |
| | $x_{1ts} \geqq T^{x}_{1ts} + 8R^{x}_{1ts}$ |
| $t_{22} \leqq t \leqq t_{23}$ | $T^{x}_{1ts} + x_{10ts} \geqq \sum_{c=7,14} cT^{x}_{13ts}$ |
| | $x_{1ts} \geqq T^{x}_{1ts} + \sum_{c=8}^{9} cR^{x}_{1ts}$ |
| $t_{23} \leqq t \leqq t_{24}$ | $T^{x}_{1ts} + x_{10ts} \geqq 14T^{x}_{13ts}$ |
| | $x_{1ts} \geqq T^{x}_{1ts} + \sum_{c=8}^{9} cR^{x}_{1ts}$ |
| $t_{24} \leqq t \leqq t_{25}$ | $T^{x}_{1ts} + x_{10ts} \geqq \sum_{c=9,14} cT^{x}_{13ts}$ |
| | $x_{1ts} \geqq T^{x}_{1ts} + \sum_{c=8}^{9} cR^{x}_{1ts}$ |
| $t_{25} \leqq t \leqq t_{26}$ | $T^{x}_{1ts} + x_{10ts} \geqq \sum_{c=9,14} cT^{x}_{13ts}$ |
| | $x_{1ts} \geqq T^{x}_{1ts} + \sum_{c=8}^{9} cR^{x}_{1ts}$ |
| $t_{26} \leqq t \leqq t_{27}$ | $T^{x}_{1ts} + x_{10ts} \geqq 9T^{x}_{13ts}$ |
| | $x_{1ts} \geqq T^{x}_{1ts} + 8R^{x}_{1ts}$ |
| $t_{27} \leqq t \leqq t_{28}$ | $T^{x}_{1ts} + x_{10ts} \geqq 9T^{x}_{13ts}$ |
| | $x_{1ts} \geqq T^{x}_{1ts}$ |

| | |
|---|---|
| $t_{28} \leqq t \leqq t_{29}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq 9\,{}_{T}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + 10\,{}_{R}x_{1ts}$ |
| $t_{29} \leqq t \leqq t_{30}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq 0$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + 10\,{}_{R}x_{1ts}$ |
| $t_{30} \leqq t \leqq t_{31}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq 0$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + 10\,{}_{R}x_{1ts}$ |
| $t_{31} \leqq t \leqq t_{32}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq 10\,{}_{T}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + 10\,{}_{R}x_{1ts}$ |
| $t_{32} \leqq t \leqq t_{33}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq 10\,{}_{T}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts}$ |
| $t_{33} \leqq t \leqq t_{34}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq 10\,{}_{T}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + 11\,{}_{R}x_{1ts}$ |
| $t_{34} \leqq t \leqq t_{35}$ | ${}_{T}x_{1ts} + x_{10ts} \geqq 10\,{}_{T}x_{13ts}$ |
| | $x_{1ts} \geqq {}_{T}x_{1ts} + 11\,{}_{R}x_{1ts}$ |

$t_{35} \leqq t \leqq t_{36}$

$$_{T}x_{1ts} + x_{10ts} \geqq {}_{10T}x_{13ts}$$

$$x_{1ts} \geqq {}_{T}x_{1ts} + \sum_{c=11}^{12} {}_{cR}x_{1ts}$$

$t_{36} \leqq t \leqq T$

$$_{T}x_{1ts} + x_{10ts} \geqq \sum_{c=10}^{12} {}_{cT}x_{13ts}$$

$$x_{1ts} \geqq {}_{T}x_{1ts} + \sum_{c=11}^{12} {}_{cR}x_{1ts}$$

## I. The Engineering Support Labor Submodel

Engineering support labor is supplied and used in exactly the same manner as engineering labor. The only difference is notational. It is included in the overall model so as to highlight the trade-off aspects of labor type usage during R&D and T&E. Since there are no real differences from the last section, no discussion will be included here. Table II-4 contains the details on the inequations.

TABLE II-4

TIME PHASED ENGINEERING SUPPORT LABOR BALANCE INEQUATIONS

| | |
|---|---|
| $0 \leqq t \leqq t_1$ | ${}_{T}x_{2ts} + x_{9ts} \geqq 3\,{}_{T}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} + \sum_{c=1}^{2,5} {}_{cR}x_{2ts}$ |
| $t_1 \leqq t \leqq t_2$ | ${}_{T}x_{2ts} + x_{9ts} \geqq \sum_{c=2}^{3} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} + \sum_{c=1,5} {}_{cR}x_{2ts}$ |
| $t_2 \leqq t \leqq t_3$ | ${}_{T}x_{2ts} + x_{9ts} \geqq \sum_{c=1}^{3,13} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} \quad \sum_{c=1,5} {}_{cR}x_{2ts}$ |
| $t_3 \leqq t \leqq t_4$ | ${}_{T}x_{2ts} + x_{9ts} \geqq \sum_{c=1}^{3,13} {}_{cR}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} + \sum_{c=1,5} {}_{cR}x_{2ts}$ |
| $t_4 \leqq t \leqq t_5$ | ${}_{T}x_{2ts} + x_{9ts} \geqq \sum_{c=1}^{3,13} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} + \sum_{c=1}^{6} {}_{cR}x_{2ts}$ |
| $t_5 \leqq t \leqq t_6$ | ${}_{T}x_{2ts} + x_{9ts} \geqq \sum_{c=1}^{2,13} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} + \sum_{c=5}^{6} {}_{cR}x_{2ts}$ |

TABLE II-4 (cont'd)

| | |
|---|---|
| $t_6 \leq t \leq t_7$ | ${}_{T}x_{2ts} + x_{9ts} \geq \sum_{c=1}^{2,13} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geq {}_{T}x_{2ts} + {}_{6R}x_{2ts}$ |
| $t_7 \leq t \leq t_8$ | ${}_{T}x_{2ts} + x_{9ts} \geq \sum_{c=1}^{2,13} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geq {}_{T}x_{2ts} + {}_{6R}x_{2ts}$ |
| $t_8 \leq t \leq t_9$ | ${}_{T}x_{2ts} + x_{9ts} \geq \sum_{c=1,13} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geq {}_{T}x_{2ts} + {}_{6R}x_{2ts}$ |
| $t_9 \leq t \leq t_{10}$ | ${}_{T}x_{2ts} + x_{9ts} \geq {}_{13T}x_{14ts}$ |
| | $x_{2ts} \geq {}_{T}x_{2ts} + {}_{6R}x_{2ts}$ |
| $t_{10} \leq t \leq t_{11}$ | ${}_{T}x_{2ts} + x_{9ts} \geq {}_{13T}x_{14ts}$ |
| | $x_{2ts} \geq {}_{T}x_{2ts} + {}_{6R}x_{2ts}$ |
| $t_{11} \leq t \leq t_{12}$ | ${}_{T}x_{2ts} + x_{9ts} \geq \sum_{c=6,13} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geq {}_{T}x_{2ts} + 6R_{x}2ts$ |
| $t_{12} \leq t \leq t_{13}$ | ${}_{T}x_{2ts} + x_{9ts} \geq \sum_{c=6,13} {}_{cT}x_{14ts}$ |
| | $x_{2ts} \geq {}_{T}x_{2ts}$ |

TABLE II-4 (cont'd)

| | |
|---|---|
| $t_{13} \leqq t \leqq t_{14}$ | $T^x{}_{2ts} + x_{9ts} \geqq \sum_{c=6,13} cT^x{}_{14ts}$ |
| | $x_{2ts} \geqq T^x{}_{2ts} + 7R^x{}_{2ts}$ |
| $t_{14} \leqq t \leqq t_{15}$ | $T^x{}_{2ts} + x_{9ts} \geqq \sum_{c=6,13} cT^x{}_{14ts}$ |
| | $x_{2ts} \geqq T^x{}_{2ts} + 7R^x{}_{2ts}$ |
| $t_{15} \leqq t \leqq t_{16}$ | $T^x{}_{2ts} + x_{9ts} \geqq \sum_{c=6,13} cT^x{}_{14ts}$ |
| | $x_{2ts} \geqq T^x{}_{2ts} + 7R^x{}_{2ts}$ |
| $t_{16} \leqq t \leqq t_{17}$ | $T^x{}_{2ts} + x_{9ts} \geqq 6T^x{}_{14ts}$ |
| | $x_{2ts} \geqq T^x{}_{2ts} + 7R^x{}_{2ts}$ |
| $t_{17} \leqq t \leqq t_{18}$ | $T^x{}_{2ts} + x_{9ts} \geqq 6T^x{}_{14ts}$ |
| | $x_{2ts} \geqq T^x{}_{2ts} + \sum_{c=7}^{8} cR^x{}_{2ts}$ |
| $t_{18} \leqq t \leqq t_{19}$ | $T^x{}_{2ts} + x_{9ts} \geqq \sum_{c=6}^{7} cT^x{}_{14ts}$ |
| | $x_{2ts} \geqq T^x{}_{2ts} + \sum_{c=7}^{8} cR^x{}_{2ts}$ |
| $t_{19} \leqq t \leqq t_{20}$ | $T^x{}_{2ts} + x_{9ts} \geqq 7T^x{}_{14ts}$ |
| | $x_{2ts} \geqq T^x{}_{2ts} + \sum_{c=7}^{8} cR^x{}_{2ts}$ |

TABLE II-4 (cont'd)

| | |
|---|---|
| $t_{20} \leq t \leq t_{21}$ | $T^{x}{}_{2ts} + x_{9ts} \geq \sum_{c=7,14} {}_{c}T^{x}{}_{14ts}$ |
| | $x_{2ts} \geq T^{x}{}_{2ts} + {}_{8}R^{x}{}_{2ts}$ |
| $t_{21} \leq t \leq t_{22}$ | $T^{x}{}_{2ts} + x_{9ts} \geq \sum_{c=7,14} {}_{c}T^{x}{}_{14ts}$ |
| | $x_{2ts} \geq T^{x}{}_{2ts} + {}_{8}R^{x}{}_{2ts}$ |
| $t_{22} \leq t \leq t_{23}$ | $T^{x}{}_{2ts} + x_{9ts} \geq \sum_{c=7,14} {}_{c}T^{x}{}_{14ts}$ |
| | $x_{2ts} \geq T^{x}{}_{2ts} + \sum_{c=8}^{9} {}_{c}R^{x}{}_{2ts}$ |
| $t_{23} \leq t \leq t_{24}$ | $T^{x}{}_{2ts} + x_{9ts} \geq {}_{14}T^{x}{}_{14ts}$ |
| | $x_{2ts} \geq T^{x}{}_{2ts} + \sum_{c=8}^{9} {}_{c}R^{x}{}_{2ts}$ |
| $t_{24} \leq t \leq t_{25}$ | $T^{x}{}_{2ts} + x_{9ts} \geq \sum_{c=9,14} {}_{c}T^{x}{}_{14ts}$ |
| | $x_{2ts} \geq T^{x}{}_{2ts} + \sum_{c=8}^{9} {}_{c}R^{x}{}_{2ts}$ |
| $t_{25} \leq t \leq t_{26}$ | $T^{x}{}_{2ts} + x_{9ts} \geq \sum_{c=9,14} {}_{c}T^{x}{}_{14ts}$ |
| | $x_{2ts} \geq T^{x}{}_{2ts} + \sum_{c=8}^{9} {}_{c}R^{x}{}_{2ts}$ |

| | |
|---|---|
| $t_{26} \leqq t \leqq t_{27}$ | $T^{x}{}_{2ts} + x_{9ts} \leqq 9T^{x}{}_{14ts}$ |
| | $x_{2ts} \leqq T^{x}{}_{2ts} + 8R^{x}{}_{2ts}$ |
| $t_{27} \leqq t \leqq t_{28}$ | $T^{x}{}_{2ts} + x_{9ts} \leqq 9T^{x}{}_{14ts}$ |
| | $x_{2ts} \leqq T^{x}{}_{2ts}$ |
| $t_{28} \leqq t \leqq t_{29}$ | $T^{x}{}_{2ts} + x_{9ts} \leqq 9T^{x}{}_{14ts}$ |
| | $x_{2ts} \geqq T^{x}{}_{2ts} + 10R^{x}{}_{2ts}$ |
| $t_{29} \leqq t \leqq t_{30}$ | $T^{x}{}_{2ts} + x_{9ts} \geqq 0$ |
| | $x_{2ts} \geqq T^{x}{}_{2ts} + 10R^{x}{}_{2ts}$ |
| $t_{30} \leqq t \leqq t_{31}$ | $T^{x}{}_{2ts} + x_{9ts} \geqq 0$ |
| | $x_{2ts} \geqq T^{x}{}_{2ts} + 10R^{x}{}_{2ts}$ |
| $t_{31} \leqq t \leqq t_{32}$ | $T^{x}{}_{2ts} + x_{9ts} \geqq 10T^{x}{}_{14ts}$ |
| | $x_{2ts} \geqq T^{x}{}_{2ts} + 10R^{x}{}_{2ts}$ |
| $t_{32} \leqq t \leqq t_{33}$ | $T^{x}{}_{2ts} + x_{9ts} \geqq 10T^{x}{}_{14ts}$ |
| | $x_{2ts} \geqq T^{x}{}_{2ts}$ |

TABLE II-4 (cont'd)

| | |
|---|---|
| $t_{33} \leqq t \leqq t_{34}$ | ${}_{T}x_{2ts} + x_{9ts} \leqq {}_{10T}x_{14ts}$ |
| | $x_{2ts} \leqq {}_{T}x_{2ts} + {}_{11R}x_{2ts}$ |
| $t_{34} \leqq t \leqq t_{35}$ | ${}_{T}x_{2ts} + x_{9ts} \leqq {}_{10T}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} + {}_{11R}x_{2ts}$ |
| $t_{35} \leqq t \leqq t_{36}$ | ${}_{T}x_{2ts} + x_{9ts} \geqq {}_{10T}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} + \sum_{c=11}^{12} {}_{cR}x_{2ts}$ |
| $t_{36} \leqq t \leqq T$ | ${}_{T}x_{2ts} + x_{9ts} \geqq \sum_{c=10}^{11} {}_{cR}x_{14ts}$ |
| | $x_{2ts} \geqq {}_{T}x_{2ts} + \sum_{c=11}^{12} {}_{cR}x_{2ts}$ |

## J. The System Operators Submodel

System operators are those individuals who take prototype hardware and operate it during test and evaluation. Some of these operators are supplied by the contractors (denoted $x_{11ts}$) and some by the government (denoted $x_{12ts}$). The government supplied operators are supplied exogenous to the firm with the state-of-nature index useful as a way of including the riskiness in actual availability. The total available in a time period and state of nature is $(x_{11ts} + x_{12ts})$.

The quantity used in any time period and state-of-nature on contract c is denoted $({}_{cT}x_{15ts})$. Of necessity when summed over all relevant contracts, it must not exceed the availability. Thus

$$x_{11ts} + x_{1\ ts} \geq \sum_{c} {}_{cT}x_{15ts}$$

Table II-5 shows the detail of this inequation over time.

## TABLE II-5

## TIME PHASED SYSTEM OPERATOR BALANCE INEQUATIONS

| | |
|---|---|
| $0 \leqq t \leqq t_1$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=2}^{3} cT^{x}15ts$ |
| $t_1 \leqq t \leqq t_2$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=2}^{3} cT^{x}15ts$ |
| $t_2 \leqq t \leqq t_3$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=1}^{3,13} cT^{x}15ts$ |
| $t_3 \leqq t \leqq t_4$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=1}^{3,13} cT^{x}15ts$ |
| $t_4 \leqq t \leqq t_5$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=1}^{3,13} cT^{x}15ts$ |
| $t_5 \leqq t \leqq t_6$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=1}^{2,13} cT^{x}15ts$ |
| $t_6 \leqq t \leqq t_7$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=1}^{2,13} cT^{x}15ts$ |
| $t_7 \leqq t \leqq t_8$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=1}^{2,13} cT^{x}15ts$ |
| $t_8 \leqq t \leqq t_9$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=1,13} cT^{x}15ts$ |
| $t_9 \leqq t \leqq t_{10}$ | $x_{11ts} + x_{12ts} \geqq 13T^{x}15ts$ |
| $t_{10} \leqq t \leqq t_{11}$ | $x_{11ts} + x_{12ts} \geqq 13T^{x}15ts$ |
| $t_{11} \leqq t \leqq t_{12}$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=6,13} cT^{x}15ts$ |

TABLE II-5 (cont'd)

| | |
|---|---|
| $t_{12} \leq t \leq t_{13}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=6,13} cTx_{15ts}$ |
| $t_{13} \leq t \leq t_{14}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=6,13} cTx_{15ts}$ |
| $t_{14} \leq t \leq t_{15}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=6,13} cTx_{15ts}$ |
| $t_{15} \leq t \leq t_{16}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=6,13} cTx_{15ts}$ |
| $t_{16} \leq t \leq t_{17}$ | $x_{11ts} + x_{12ts} \geq 6Tx_{15ts}$ |
| $t_{17} \leq t \leq t_{18}$ | $x_{11ts} + x_{12ts} \geq 6Tx_{15ts}$ |
| $t_{18} \leq t \leq t_{19}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=6}^{7} cTx_{15ts}$ |
| $t_{19} \leq t \leq t_{20}$ | $x_{11ts} + x_{12ts} \geq 7Tx_{15ts}$ |
| $t_{20} \leq t \leq t_{21}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=7,14} cTx_{15ts}$ |
| $t_{21} \leq t \leq t_{22}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=7,14} cTx_{15ts}$ |
| $t_{22} \leq t \leq t_{23}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=7,14} cTx_{15ts}$ |
| $t_{23} \leq t \leq t_{24}$ | $x_{11ts} + x_{12ts} \geq 14Tx_{15ts}$ |
| $t_{24} \leq t \leq t_{25}$ | $x_{11ts} + x_{12ts} \geq \sum_{c=9,14} cTx_{15ts}$ |

TABLE II-5 (cont'd)

| | |
|---|---|
| $t_{25} \leqq t \leqq t_{26}$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=9,4} {}_{cT}x_{15ts}$ |
| $t_{26} \leqq t \leqq t_{27}$ | $x_{11ts} + x_{12ts} \geqq {}_{9T}x_{15ts}$ |
| $t_{27} \leqq t \leqq t_{28}$ | $x_{11ts} + x_{12ts} \geqq {}_{9T}x_{15ts}$ |
| $t_{28} \leqq t \leqq t_{29}$ | $x_{11ts} + x_{12ts} \geqq {}_{9T}x_{15ts}$ |
| $t_{29} \leqq t \leqq t_{30}$ | $x_{11ts} + x_{12ts} \geqq 0$ |
| $t_{30} \leqq t \leqq t_{31}$ | $x_{11ts} + x_{12ts} \geqq 0$ |
| $t_{31} \leqq t \leqq t_{32}$ | $x_{11ts} + x_{12ts} \geqq {}_{10T}x_{15ts}$ |
| $t_{32} \leqq t \leqq t_{33}$ | $x_{11ts} + x_{12ts} \geqq {}_{10T}x_{15ts}$ |
| $t_{33} \leqq t \leqq t_{34}$ | $x_{11ts} + x_{12ts} \geqq {}_{10T}x_{15ts}$ |
| $t_{34} \leqq t \leqq t_{35}$ | $x_{11ts} + x_{12ts} \geqq {}_{10T}x_{15ts}$ |
| $t_{35} \leqq t \leqq t_{36}$ | $x_{11ts} + x_{12ts} \geqq {}_{10T}x_{15ts}$ |
| $t_{36} \leqq t \leqq T$ | $x_{11ts} + x_{12ts} \geqq \sum_{c=10}^{11} {}_{cT}x_{15ts}$ |

K. The Administrative Labor Submodel

Administrative labor is used in all the operations of the contractor is order to provide the middle management of the corporation and its support. Usage aspects are considered first, then the supply of administrators is considered and finally the necessary physical balance between them.

Administrative labor is used in the warehouse-inventory operations $({}_{w}x_{7ts})$, the research and development operation on each contract $({}_{cR}x_{7ts})$, the test and evaluation operations on each contract, $({}_{cT}x_{7ts})$, the manufacturing operations on each contract $({}_{cM}x_{7ts})$, and in commercial production $({}_{\theta M}x_{7ts})$. The total usage over all relevant contracts is

$${}_{w}x_{7ts} + \sum_{c}({}_{cr}x_{7ts} + {}_{cT}x_{7ts} + {}_{cM}x_{7ts}) + {}_{\theta M}x_{7ts}$$

Administratove labor is purchased by the contractor in the labor market. The quantity purchased in time period $\underline{t}$ and state-of-nature $\underline{s}$ is denoted $x_{7ts}$. As before usage cannot exceed supply so

$$x_{7ts} \geqq {}_{w}x_{7ts} + \sum_{c}({}_{cr}x_{7ts} + {}_{cT}x_{7ts} + {}_{cM}x_{7ts}) + {}_{\theta M}x_{7ts}.$$

Table II-6 contains the details of the time phasing of this balance inequation.

Finally, note that the contractor chooses the quantity of every variable discussed in every time period and state-of-nature.

## TABLE II-6

## TIME PHASED ADMINISTRATIVE LABOR BALANCE INEQUATIONS

| | |
|---|---|
| $0 \leqq t \leqq t_1$ | $x_{7ts} \geqq w^x_{7ts} + \sum_{c=1}^{2,5} {}_cR^x_{7ts} + \sum_{c=2}^{3} {}_cT^x_{7ts} + {}_4M^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_1 \leqq t \leqq t_2$ | $x_{7ts} \geqq w^x_{7ts} + \sum_{c=1,5} {}_cR^x_{7ts} + \sum_{c=2}^{3} {}_cT^x_{7ts} + {}_4M^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_2 \leqq t \leqq t_3$ | $x_{7ts} \geqq w^x_{7ts} + \sum_{c=1,5} {}_cR^x_{7ts} + \sum_{c=1}^{3,13} {}_cT^x_{7ts} + {}_4M^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_3 \leqq t \leqq t_4$ | $x_{7ts} \geqq w^x_{7ts} + \sum_{c=1,5} {}_cR^x_{7ts} + \sum_{c=1}^{3,13} {}_cT^x_{7ts} + \sum_{c=3}^{4} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_4 \leqq t \leqq t_5$ | $x_{7ts} \geqq w^x_{7ts} + \sum_{c=5}^{6} {}_cR^x_{7ts} + \sum_{c=1}^{3,13} {}_cT^x_{7ts} + \sum_{c=3}^{4} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_5 \leqq t \leqq t_6$ | $x_{7ts} \geqq w^x_{7ts} + \sum_{c=5}^{6} {}_cR^x_{7ts} + \sum_{c=1}^{2,13} {}_cT^x_{7ts} + \sum_{c=3}^{4} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_6 \leqq t \leqq t_7$ | $x_{7ts} \geqq w^x_{7ts} + {}_6R^x_{7ts} + \sum_{c=1}^{2,13} {}_cT^x_{7ts} + \sum_{c=2}^{4} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_7 \leqq t \leqq t_8$ | $x_{7ts} \geqq w^x_{7ts} + {}_6R^x_{7ts} + \sum_{c=1}^{2,13} {}_cT^x_{7ts} + \sum_{c=1}^{4} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_8 \leqq t \leqq t_9$ | $x_{7ts} \geqq w^x_{7ts} + {}_6R^x_{7ts} + \sum_{c=1,13} {}_cT^x_{7ts} + \sum_{c=1}^{4} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_9 \leqq t \leqq t_{10}$ | $x_{7ts} \geqq w^x_{7ts} + {}_6R^x_{7ts} + {}_{13}T^x_{7ts} + \sum_{c=1}^{4} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_{10} \leqq t \leqq t_{11}$ | $x_{7ts} \geqq w^x_{7ts} + {}_6R^x_{7ts} + {}_{13}T^x_{7ts} + \sum_{c=1}^{3} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |
| $t_{11} \leqq t \leqq t_{12}$ | $x_{7ts} \geqq w^x_{7ts} + {}_6R^x_{7ts} + \sum_{c=6,13} {}_cT^x_{7ts} + \sum_{c=1}^{3} {}_cM^x_{7ts} + {}_\theta M^x_{7ts}$ |

TABLE II-6 (cont'd)

| | |
|---|---|
| $t_{12} \leqq t \leqq t_{13}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + \quad + \sum_{c=6,13} {}_{cT}x_{7ts} + \sum_{c=1}^{3} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{13} \leqq t \leqq t_{14}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + {}_{7R}x_{7ts} + \sum_{c=6,13} {}_{cT}x_{7ts} + \sum_{c=1}^{3} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{14} \leqq t \leqq t_{15}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + {}_{7R}x_{7ts} + \sum_{c=6,13} {}_{cT}x_{7ts} + \sum_{c=1}^{2} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{15} \leqq t \leqq t_{16}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + {}_{7R}x_{7ts} + \sum_{c=6,13} {}_{cT}x_{7ts} + \sum_{c=1}^{2,6} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{16} \leqq t \leqq t_{17}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + {}_{7R}x_{7ts} + {}_{6T}x_{7ts} + \sum_{c=2,6} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{17} \leqq t \leqq t_{18}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + \sum_{c=7}^{8} {}_{cR}x_{7ts} + {}_{6T}x_{7ts} + \sum_{c=2,6} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{18} \leqq t \leqq t_{19}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + \sum_{c=7}^{8} {}_{cR}x_{7ts} + \sum_{c=6}^{7} {}_{cT}x_{7ts} + {}_{6M}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{19} \leqq t \leqq t_{20}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + \sum_{c=7}^{8} {}_{cR}x_{7ts} + {}_{7T}x_{7ts} + {}_{6M}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{20} \leqq t \leqq t_{21}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + {}_{8R}x_{7ts} + \sum_{c=7,14} {}_{cT}x_{7ts} + {}_{6M}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{21} \leqq t \leqq t_{22}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + {}_{8R}x_{7ts} + \sum_{c=7,14} {}_{cT}x_{7ts} + \sum_{c=6}^{7} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{22} \leqq t \leqq t_{23}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + \sum_{c=8}^{9} {}_{cR}x_{7ts} + \sum_{c=7,14} {}_{cT}x_{7ts} + \sum_{c=6}^{7} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{23} \leqq t \leqq t_{24}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + \sum_{c=8}^{9} {}_{cR}x_{7ts} + {}_{14T}x_{7ts} + \sum_{c=6}^{7} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |
| $t_{24} \leqq t \leqq t_{25}$ | $x_{7ts} \geqq {}_{w}x_{7ts} + \sum_{c=8}^{9} {}_{cR}x_{7ts} + \sum_{c=9,14} {}_{cT}x_{7ts} + \sum_{c=6}^{7} {}_{cM}x_{7ts} + {}_{\theta M}x_{7ts}$ |

TABLE II-6 (cont'd)

$$t_{25} \leq t \leq t_{26} \quad x_{7ts} \geq w^x{}_{7ts} + \sum_{c=8}^{9} {}_cR^x{}_{7ts} + \sum_{c=9,14} {}_cT^x{}_{7ts} + {}_7M^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{26} \leq t \leq t_{27} \quad x_{7ts} \geq w^x{}_{7ts} + {}_8R^x{}_{7ts} + {}_9T^x{}_{7ts} + \sum_{c=7,9} {}_cM^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{27} \leq t \leq t_{28} \quad x_{7ts} \geq w^x{}_{7ts} + \quad + {}_9T^x{}_{7ts} + \sum_{c=7,9} {}_cM^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{28} \leq t \leq t_{29} \quad x_{7ts} \geq w^x{}_{7ts} + {}_{10}R^x{}_{7ts} + {}_9T^x{}_{7ts} + \sum_{c=7,9} {}_cM^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{29} \leq t \leq t_{30} \quad x_{7ts} \geq w^x{}_{7ts} + {}_{10}R^x{}_{7ts} + \quad + \sum_{c=7,9} {}_cM^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{30} \leq t \leq t_{31} \quad x_{7ts} \geq w^x{}_{7ts} + {}_{10}R^x{}_{7ts} + \quad + {}_9M^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{31} \leq t \leq t_{32} \quad x_{7ts} \geq w^x{}_{7ts} + {}_{10}R^x{}_{7ts} + {}_{10}T^x{}_{7ts} + {}_9M^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{32} \leq t \leq t_{33} \quad x_{7ts} \geq w^x{}_{7ts} + \quad + {}_{10}T^x{}_{7ts} + {}_9M^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{33} \leq t \leq t_{34} \quad x_{7ts} \geq w^x{}_{7ts} + {}_{11}R^x{}_{7ts} + {}_{10}T^x{}_{7ts} + {}_9M^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{34} \leq t \leq t_{35} \quad x_{7ts} \geq w^x{}_{7ts} + {}_{11}R^x{}_{7ts} + {}_{10}T^x{}_{7ts} + \sum_{c=9}^{10} {}_cM^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{35} \leq t \leq t_{36} \quad x_{7ts} \geq w^x{}_{7ts} + \sum_{c=11}^{12} {}_cR^x{}_{7ts} + {}_{10}T^x{}_{7ts} + \sum_{c=9}^{10} {}_cM^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

$$t_{36} \leq t \leq T \quad x_{7s} \geq w^x{}_{7ts} + \sum_{c=11}^{12} {}_cR^x{}_{7ts} + \sum_{c=10}^{11} {}_cT^x{}_{7ts} + \sum_{c=9}^{10} {}_cM^x{}_{7ts} + {}_\theta M^x{}_{7ts}$$

## L. The Manufacturing Labor Submodel

Manufacturing labor is used in manufacturing and warehouse-inventory operations to provide the labor for the complete range of material handling, inspection, assembly, etc. Usage aspects are detailed first, then supply aspects are discussed and finally the relationship of the two are considered.

Manufacturing labor is used in warehouse-inventory operations $({}_{w}x_{8ts})$, government contract manufacturing $({}_{cM}x_{8ts})$ and commercial production $({}_{\theta M}x_{7ts})$. The total usage over all relevant contracts is

$$ {}_{w}x_{8ts} + \sum_{c} {}_{cM}x_{8ts} + {}_{\theta M}x_{8ts} $$

Manufacturing labor is purchased by the contractor in the labor market. The quantity purchased is denoted $x_{8ts}$. Since physical usage over all relevant contracts is

$$ {}_{w}x_{8ts} + \sum_{c} {}_{cM}x_{8ts} + {}_{\theta M}x_{8ts} $$

Manufacturing labor is purchased by the contractor in the labor market. The quantity purchase is denoted $x_{8ts}$. Since physical usage must not exceed supply.

$$ x_{8ts} \geq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + \sum_{c} {}_{cM}x_{8ts} $$

Table II-7 contains the details of the time phasing of this balance inequation. Note that the contractor chooses the quantity of every variable in each time period and state-of-nature.

TABLE II-7

TIME PHASED MANUFACTURING LABOR BALANCE INEQUATIONS

| | |
|---|---|
| $0 \leq t \leq t_1$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + 4M^{x}{}_{8ts}$ |
| $t_1 \leq t \leq t_2$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + 4M^{x}{}_{8ts}$ |
| $t_2 \leq t \leq t_3$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + 4M^{x}{}_{8ts}$ |
| $t_3 \leq t \leq t_4$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=3}^{4} cM^{x}{}_{8ts}$ |
| $t_4 \leq t \leq t_5$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=3}^{4} cM^{x}{}_{8ts}$ |
| $t_5 \leq t \leq t_6$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=3}^{4} cM^{x}{}_{8ts}$ |
| $t_6 \leq t \leq t_7$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=2}^{4} cM^{x}{}_{8ts}$ |
| $t_7 \leq t \leq t_8$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=1}^{4} cM^{x}{}_{8ts}$ |
| $t_8 \leq t \leq t_9$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=2}^{4} cM^{x}{}_{8ts}$ |
| $t_9 \leq t \leq t_{10}$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=1}^{4} cM^{x}{}_{8ts}$ |
| $t_{10} \leq t \leq t_{11}$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=1}^{3} cM^{x}{}_{8ts}$ |
| $t_{11} \leq t \leq t_{12}$ | $x_{8ts} \geq w^{x}{}_{8ts} + \theta M^{x}{}_{8ts} + \sum_{c=1}^{3} cM^{x}{}_{8ts}$ |

TABLE II-7 (cont'd)

| | |
|---|---|
| $t_{12} \leqq t \leqq t_{13}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=1}^{3} cM^{x}8ts$ |
| $t_{13} \leqq t \leqq t_{14}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=1}^{3} cM^{x}8ts$ |
| $t_{14} \leqq t \leqq t_{15}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=1}^{2} cM^{x}8ts$ |
| $t_{15} \leqq t \leqq t_{16}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=1}^{2,6} cM^{x}8ts$ |
| $t_{16} \leqq t \leqq t_{17}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=2,6} cM^{x}8ts$ |
| $t_{17} \leqq t \leqq t_{18}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=2,6} cM^{x}8ts$ |
| $t_{18} \leqq t \leqq t_{19}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + 6M^{x}8ts$ |
| $t_{19} \leqq t \leqq t_{20}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + 6M^{x}8ts$ |
| $t_{20} \leqq t \leqq t_{21}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + 6M^{x}8ts$ |
| $t_{21} \leqq t \leqq t_{22}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=6}^{7} cM^{x}8ts$ |
| $t_{22} \leqq t \leqq t_{23}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=6}^{7} cM^{x}8ts$ |
| $t_{23} \leqq t \leqq t_{24}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=6}^{7} cM^{x}8ts$ |
| $t_{24} \leqq t \leqq t_{25}$ | $x_{8ts} \geqq w^{x}8ts + \theta M^{x}8ts + \sum_{c=6}^{7} cM^{x}8ts$ |

TABLE II-7 (cont'd)

| | |
|---|---|
| $t_{25} \leqq t \leqq t_{26}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + {}_{7M}x_{8ts}$ |
| $t_{26} \leqq t \leqq t_{27}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + \sum_{c=7,9} {}_{cM}x_{8ts}$ |
| $t_{27} \leqq t \leqq t_{28}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + \sum_{c=7,9} {}_{cM}x_{8ts}$ |
| $t_{28} \leqq t \leqq t_{29}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + \sum_{c=7,9} {}_{cM}x_{8ts}$ |
| $t_{29} \leqq t \leqq t_{30}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + \sum_{c=7,9} {}_{cM}x_{8ts}$ |
| $t_{30} \leqq t \leqq t_{31}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + {}_{9M}x_{8ts}$ |
| $t_{31} \leqq t \leqq t_{32}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + {}_{9M}x_{8ts}$ |
| $t_{32} \leqq t \leqq t_{33}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + {}_{9M}x_{8ts}$ |
| $t_{33} \leqq t \leqq t_{34}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + {}_{9M}x_{8ts}$ |
| $t_{34} \leqq t \leqq t_{35}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + \sum_{c=9}^{10} {}_{cM}x_{8ts}$ |
| $t_{35} \leqq t \leqq t_{36}$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta M}x_{8ts} + \sum_{c=9}^{10} {}_{cM}x_{8ts}$ |
| $t_{36} \leqq t \leqq T$ | $x_{8ts} \geqq {}_{w}x_{8ts} + {}_{\theta}x_{8ts} + \sum_{c=9}^{10} {}_{cM}x_{8ts}$ |

M. The Corporate Headquarters Submodel

Corporate Headquarters represents the top management of the contractor and all its support activities. For simplicity, it is considered only a labor using organization without a need for plant and equipment services. This selling and administrative labor is denoted by $x_{16ts}$ and is a decision variable for the management. The activity represented by the corporate headquarters includes the planning, coordinating and directing activities of the corporation. If the corporate is thought of as a multilevel decentralized entity using a decentralized procedure, then headquarters is the central planning board. Since this submodel is not complex, no diagram is provided.

N. The Contractor's Interfaces With Suppliers and Customers.

In this section the interactions of the contractor with others in the economic system are discussed. Thus the nature of the market interactions of the contractor with suppliers and customers is considered. First the various labor markets are considered, then the markets for material and purchased parts are discussed. Following that, the subcontracting market and plant and equipment markets are detailed. After that the commercial and government customer markets are considered. Finally the market for short term debts (money markets), long term debt (capital markets) and equity (stock markets) are discussed. The regulatory interaction with the Renegotiation Board is discussed in Section II, P.

The labor markets are assured to fall into two categories. First the markets for engineering labor, engineering support labor, system operators and administrative labor are of one type. Second the markets for selling and administrative labor and manufacturing labor are another type. These will be discussed in turn.

The first category of engineering labor, engineering support labor, system operators and administrative labor are markets where the contractor is assumed to perceive that contractor activities will not perceptively influence the market price. This is in effect an assumption that these markets operate in a purely competitive manner. Thus, the only environmental variable of interest to the contractor is the market price itself. These are denoted as engineering labor wage rate ($W_{1ts}$), engineering support wage rate ($W_{2ts}$), systems operators wage rate ($W_{11ts}$) and administrative wage rate ($W_{7ts}$). Notice that these wage rates are time and state-of-nature indexed so that the contractor can consider labor over time and in various conditions of risk (e.g., inflation of selected magnitudes).

The second category of selling and admistrative labor, and manufacturing labor are markets where the contractor is assumed to perceive that contractor actions will have a perceptible influence on market price. In the case of the manufacturing labor a union can be assumed, such that the contractor perceives a supply curve of labor as a function of the wage rate. This union offer curve is assumed to be sloping, i.e.

$$\underset{\text{(supplied)}}{x_8} = g_8(W_8),\ g_8' > 0$$

The selling and administrative labor market is not a unionized one, but is considered to be a specialty market with few buyers of such services and it is also assumed a fewness of suppliers exists. Thus, the contractor also perceives a supply curve here which is also assumed upward sloping, i.e.,

$$\underset{\text{(supplied)}}{x_{16}} = g_{16}(W_{16}),\ g_{16}' > 0$$

Again time and risk matters are important so the complete equations are

$$x_{8ts} = g_{8ts}(W_{8ts}),\ g^{1}_{8ts} > 0$$
(Supply)

$$x_{16ts} = g_{16ts}(W_{16ts}),\ g^{1}_{16ts} > 0$$
(Supply)

Here rivalrous action on the part of other users as well as the union is included in the risk aspect.

The markets for material and purchased parts are assumed to be structured such that the contractor perceives little influence from the contractor's actions. Thus, this purely competitive market requires the contractor to only be concerned with the market price. For material this is $W_{3ts}$ and for purchased parts $W_{4ts}$. Again time and risk indices permit the discussion of multiperiod planning and such conditions of rise as material and purchase parts price inflation.

The subcontracting and plant and equipment markets are structured such that there are few suppliers and few users. This bilateral oligopoly arrangement is represented by a contractor perceived offer curve for each item. Thus, including time and risk indices, for subcontracted parts the equation is

$$x_{5ts} = g_{5ts}(W_{5ts}),\ g'_{5ts} > 0$$
(Supply)

While for plant and equipment the equation is

$$\dot{k}_{1ts} = h_{1ts}(W_{k_{1ts}}),\ h'_{1ts} > 0$$
(Supply)

The risk index here includes not only inflationary matters but also rivalrousness action on the part of suppliers and users.

The commercial customer market is assumed to be perceived by the contractor as monopolistically competitive. Thus a demand curve for the commercial product is assumed. Formally, it is

$$_{\theta}q_{ts} = f_{\theta}({}_{\theta}P_{ts}),\ f'_{\theta} < 0$$

This downward sloping demand curve could also be interpreted in the context of an oligopolistic market structure as the contractor perceived "piece of the action." The time index permits multiperiod planning with time varying demand and the risk index permits altervative rivalrous actions to be incorporated.

The government market is characterized by a bilateral monopoly for the existing contracts and oligopolistic rivalry for monopsonistically offered contracts in the future. For simplicity in developing the model, the contractor is assumed to perceive no influence by his own actions on the contract terms. In all cases the contractor perceives a contract with normal as well as incentive profit items. The time dating of the contracts was shown earlier in Figure II-1. The risk index on current projects incorporates the various types of government induced risk such as quantity changes, budget nonavailability and the like. On future contracts the risk index includes these aspects as well as rivals action. The details on each government contract is shown in the financial submodel (section II,O).

Government furnished parts, plant and equipment, engineering labor, engineering support labor, and system operators are perceived by the contractor as time dated and risky but beyond his control to influence. Thus, the "market" is a quantity availability one with time and risk indices to account for government actions that are "nonresponsive."

Finally, the contractor must interact in the world of finance via short term debt (denoted $l_{1ts}$), long term debt (denoted $l_{2ts}$) and equity (denoted $W_{ts}$) instruments. The first two of these markets is assumed purely competitive. Thus only the market price is of interest to the contractor. These prices are denoted $w_{l_2 ts}$, and $w_{l_3 ts}$ respectively. Note that these assumptions abstract from using debt-equity ratios and dividend pay out rates as determinents of a firm's cost of capital by type of investment. The price of equity is assumed to be a function of the dividends paid in the immediately past period. This is denoted $w_{\theta ts}(D_{t-1,s})$. This function is such that if dividends in t-1 are zero, then share price is not driven to zero.

## O. The Finance Submodel

The contractor is assumed to have an accounting system with the usual balance sheets and income statement. There is latitude in the model for considerable financial management. Thus, for example, the contractor must decide on the amount of short and long term debt to issue, the amount of capital stock to issue, and the amount of dividends to pay. Also the contractor must control the timing of the cash flows. In this section of the paper the accounting is used to discuss those aspects of financial management considered pertinent to the contractor.

The contractor balance sheet and income statement are shown in in Figures II-6 and II-7, respectively. A statement of retaining earnings is included on Figure II-7 for clarity. The reader will note that the symbols for each entry are defined on the figures. For simplicity of discussion, it is assumed that there are no other accounts but those shown on Figures II-6 and II-7. Again for ease of exposition and since it will not change any of the results in this paper, the time periods of the model are also the accounting periods for the contractor. In the following paragraphs the various transactions of the firm are discussed and the respective accounting entry shown. Figures II-8 through 11-16 contained toward the end of this section generically show the overall accounts with only the transaction entries recorded. Note that a risk index is needed to indicate the accounting entries and financial actions in each state-of-nature.

### Commercial Sales Revenue ($I_1$)

Assume that the commercial products manufactured during period t are delivered to the customer that period. Also assume that the

| ASSETS | | LIABILITIES |
|---|---|---|
| CASH . . . . . . . . . . . . | $A_{1ts}$ | $L_{1ts}$ . . . . . .ACCOUNTS PAYABLE |
| ACCOUNTS RECEIVABLE. . . . | $A_{2ts}$ | $L_{2ts}$ . . . . . . . SHORT TERM DEBT |
| INVENTORY. . . . . . . . . . | $A_{3ts}$ | $L_{3ts}$ . . . . . . . LONG TERM DEBT |
| PLANT & EQUIPMENT. . . . . | $A_{4ts}$ | |
| LESS: ACCUMULATED DEPRECIATION . . .$A_{5ts}$ | $A_{6ts}$ | **OWNERSHIP EQUITY** |
| | | $W_{1ts}$ . . . . . . . CAPITAL STOCK |
| | | $W_{2ts}$ . . . . . RETAINED EARNINGS |
| TOTAL ASSETS . . . . . . . . | $A_{ts}$ | $Z_{ts}$ . .TOTAL LIABILITIES & OWNERSHIP |

FIGURE II-6

THE CONTRACTOR'S BALANCE SHEET

INCOME STATEMENT:

| | | |
|---|---|---|
| COMMERCIAL SALES REVENUE . . . . . . . . . . . . . | $I_{1ts}$ | |
| GOVERNMENT SALES REVENUE . . . . . . . . . . . . . | $I_{2ts}$ | |
| TOTAL REVENUE . . . . . . . . . . . . . . . . . . . . | | $I_{3ts}$ |
| COST OF GOODS SOLD . . . . . . . . . . . . . . . . | $I_{4ts}$ | |
| GROSS MARGIN . . . . . . . . . . . . . . . . . . . . | | $I_{5ts}$ |
| LESS SELLING AND ADMINISTRATIVE EXPENSES . . . | $I_{6ts}$ | |
| OPERATING PROFIT . . . . . . . . . . . . . . . . . . . | | $EBIT_{ts}$ |
| LESS NON-OPERATING EXPENSES | | |
| DEBT INTEREST EXPENSE . . . . . . . . . | $I_{7ts}$ | |
| INCOME TAX EXPENSE . . . . . . . . . . . | $I_{8ts}$ | |
| TOTAL NON-OPERATING EXPENSES . . . . . . . . . | | $I_{9ts}$ |
| NET INCOME . . . . . . . . . . . . . . . . . . . . | | $EAIT_{ts}$ |

STATEMENT OF RETAINED EARNINGS:

| | |
|---|---|
| RETAINED EARNINGS AT BEGINNING OF PERIOD . . | $W_{2t-1s}$ |
| ADD: NET INCOME . . . . . . . . . . . . . . . . . . | $EAIT_{t-1s}$ |
| LESS: CASH DIVIDENDS . . . . . . . . . . . . . | $D_{t-1s}$ |
| RETAINED EARNINGS AT END OF PERIOD . . . . . | $W_{2ts}$ |

FIGURE II-7

THE CONTRACTOR'S INCOME STATEMENT
AND RETAINED EARNINGS STATEMENT

customer is billed upon delivery. The accounting system of the contractor is assumed to be structured so as to recognize revenue from commercial sales upon delivery. It is assumed that the customer's payment is received in the following period to delivery (ie, t+1). This implies that periods are not too long. The entries are as follows:

| | | |
|---|---|---|
| Commercial Sales Revenue in period t and state-of-nature s | $\theta^{P}_{ts}\ \theta^{q}_{ts}$ | (increase) |
| and | | |
| Accounts Receivable in period t and state-of-nature s due to commercial sales | $\theta^{P}_{ts}\ \theta^{q}_{ts}$ | (increase) |

And also in period t the following transactions occur due to commercial sales during period t-1

| | | |
|---|---|---|
| Accounts Receivable in period t and state-of-nature s due to commercial sales | $\theta^{P}_{t-1,s}\ \theta^{q}_{t-1,s}$ | (decrease) |
| and | | |
| Cash in period t and state-of-nature s due to commercial sales | $\theta^{P}_{t-1,s}\ \theta^{q}_{t-1,s}$ | (increase) |

Government Sales Revenue ($I_2$)

The sales revenue from government contracts is based on the nature of each contract existing at a particular date. As discussed before, it is assumed that all government contracts have the same general form, but the parameter of the contract may vary in value from contract to contract. Thus, the contract is assumed to provide a normal profit and incentive profit for costs, schedule, and performance. In structure, then, the profit is

[normal profit] + [cost based incentive profit] + [schedule based incentive profit] + [performance based incentive profit]

Each of these will be discussed in turn.

Normal profit on contract c is denoted $\Pi_c$. In reality it is a result of negotiation and involves such factors as the weighted guidelines. For ease of exposition of the general model, it is assumed that the contractor perceives this as set by the government with essentially no influence from the contractor. This assumption is one of monopsonistic behavior by the government. Thus, one would expect this to apply to systems that are basically purely DOD and where commercial sales are a small part of the overall business of the contractor. Note that for alternative states-of-nature, in this case monopsonistic governmental action, normal profit on a contract is denoted $\Pi_{cs}$.

The cost-based incentive profit is calculated by assuming the contractor perceives that the government sets a "target cost," ${}_c\bar{C}_s$, for contract c in each state-of-nature. Here alternative states-of-nature represent alternative possible governmental actions with respect to "target cost." Note that the "target cost" on existing contacts is known with certainty but for ease of notation all contracts will have the risk index s. If actual costs in period t on contract c in state-of-nature s is denoted ${}_cC_{ts}$, then any cost savings would be ${}_c\bar{C}_s - \sum_{t'}^{t''} {}_cC_{ts}$ where the generic contract begins at t' and ends at t". Assume there is a sharing ratio of such savings denoted b on each contract and each alternate state-of-nature. Then any incentive profit (or loss) would be

$$ {}_cb_s\left\{{}_c\bar{C}_s - \sum_{t=t'}^{t''} {}_cC_{ts}\right\} $$

The performance based incentive profit is calculated by assuming the contractor perceives that the government provides a set of performance targets that must be compared with measured performance. If the targets are denoted ${}_c\bar{z}_{1s}, \ldots {}_c\bar{z}_{Bs}$ for contract c and state-of-nature s, and actual measured performance is ${}_{c}z_{1s}, \ldots, {}_{c}z_{Bs}$ which occurs in time at the end ot the test and evaluation phase. Then performance improvement for a specific type of performance is ${}_{c}z_{is} - {}_{c}\bar{z}_{is}$. Assume that the government is perceived by the contractor to set a weight which converts performance into dollars and also sets the sharing rat between the contractor and the government, then overall the incentive profit is

$$\sum_{1=1}^{B} {}_{c}\gamma_{is}\left({}_{c}z_{is} - {}_{c}\bar{z}_{is}\right)$$

The schedule based incentive profit is calculated by assuming the contractor perceives the government sets a time period by time period delivery schedule for the system $({}_{c}\bar{q}_{ts})$. Then based on period by period comparison of actual $({}_{c}q_{ts})$ and planned the incentive profit is computed using a government set sharing ratio and a coversion factor $({}_{c}\epsilon_{s})$ from quantity of output to profit dollars. The term in symbols is

$$ {}_{c}\epsilon_{s} \sum_{t=t'}^{t''} \left({}_{c}q_{ts} - {}_{c}\bar{q}_{ts}\right).$$

Now that the details of a generic contract profit computation has been discussed, it is time to consider the recognition by the contractor of that profit within the accounting system.

Normal profit on a government contract is paid at the end of the contract. However, the contractor is assumed to recognize normal profit as the work progresses. Note that these two assumptions about the nature of government business imply that any payment per unit at delivery does not include any portion of the normal profit. Further, it is assumed that there are progress payments on each government contract. which are computed as a fraction of costs incurred in a time period. Thus progress payments in the model are not based on a work-completed measurement system. However, the model specification of progress payments includes work completed measurement to the degree that costs accrued are correlated with work completed. The model speification was chosen with the understanding that this correlation is high. Normal profit recognition is assumed to be in the same proportion as progress payments are of the proportion of total costs on the contract incurred in the time period. As before, let ${}_cC_{ts}$ be the incurred or actual costs on contract c at time t and in state-of-nature s. Then over the life of the contract total costs are $\sum_{t-t'}^{t''} {}_cC_{ts}$. The proportion of total costs incurred in period t in state-of-nature s is then

${}_cC_{ts} \Big/ \sum_{t=t'}^{t''} {}_cC_{ts}$. If it is assumed ;that the fraction of period costs paid as progress payments is $\beta_{cs}$, then the fraction of normal profits recognized in period t and state-of-nature s on contract c is

$$\left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right] \Pi_{cs} \equiv {}_c\Pi_{ts}$$

It is assumed that this is billed to the government in period t. Thus the accounting entries are:

| | | |
|---|---|---|
| Accounts Receivable in period t and state-of-nature s due to contract c | ${}_c\Pi_{ts}$ | (increase) |
| Government sales revenue from contract c in period t and state-of-nature nature s | ${}_c\Pi_{ts}$ | (increase) |

And at the end of the contract (generically period t") the following occurs. For simplicity all contractor and government actions are assumed to occur in period t".

Cash in period t" and state-of-nature s due to contract c $\quad \sum_{t=t'}^{t''-1} {}_c\Pi_{ts}$ (increase)

$\quad + (\Pi_{cs} - \sum_{t=t'}^{t''-1} {}_c\Pi_{ts})$

Accounts Receivable in period t and state of nature s due to contract c $\quad \sum_{t=t'}^{t''-1} {}_c\Pi_{ts}$ (decrease)

Government sales revenue from contract c in period t and state-of-nature s $\quad (\Pi_{cs} - \sum_{t=t'}^{t''-1} {}_c\Pi_{ts})$ (increase)

As noted in the above discussion progress payments exist and are a fixed fraction of the costs incurred in period t in state-of-nature s. This is symbolized as

$$\beta_{cs} \; {}_cC_{ts}$$

It is assumed that the contractor bills and recognizes contract costs in full when they are incurred. The accounting entries for this are

Accounts Receivable in period t and state-of-nature s due to contract c $\quad {}_cC_{ts}$ (increase)

Government Sales Revenue on contract c in period t and state-of-nature s $\quad {}_cC_{ts}$ (increase)

This latter entry accounts for the fact that the revenue from the government contract includes profit of all types and the allowable costs incurred. It is assumed that the progress payments for the costs incurred in period t are forthcoming from the government in period t + 1. The accounting entries for progress payments during the contract, except for the termination period are

Cash in period t and state-of-nature s due to contract c $\quad \beta_{cs} \; {}_cC_{(t-1)s}$ (increase)

Accounts Receivable in period t and state-of-nature s due to contract c $\quad \beta_{cs} \; {}_cC_{(t-1)s}$ (decrease)

At the end of the contract the government pays in cash all the allowable costs incurred but not yet paid in the form of progress payments. For simplicity, this is assumed to occur in period t" the last period of the contract.

| | | |
|---|---|---|
| Cash in period t" and state-of-nature s due to contract c | $(1-\beta_{cs})\sum_{t=t'}^{t''-1} {}_cC_{ts} + {}_cC_{t''s}$ | (increase) |
| Accounts Receivable in period t" and state-of-natures s due to contract c | $(1-\beta_{cs})\sum_{t=t'}^{t''-1} {}_cC_{ts}$ | (decrease) |
| Government Sales Revenue on contract c in period t" and state-of-nature s | ${}_cC_{t''s}$ | (increase) |

Incentive profit based on costs is the next transaction to be accounted for within the contractor's accounting system. The incentive profit or loss from the existence of a cost saving incentive term in the contract is as discussed earlier:

$$ {}_cb_s \left\{ {}_c\bar{C}_s - \sum_{t=t'}^{t''} {}_cC_{ts} \right\} $$

This numerical quantity is entered into the accounting system in period t", the termination period of the contract, as

| | | |
|---|---|---|
| Cash in period t" and state-of-nature s due to contract c | ${}_cb_s \left\{ {}_c\bar{C}_s - \sum_{t-t'}^{t''} {}_cC_{ts} \right\}$ | (increase) |
| Government Sales Revenue on contract c in period t" and state-of-nature s | ${}_cb_s \left\{ {}_c\bar{C}_s - \sum_{t-t'}^{t''} {}_cC_{ts} \right\}$ | (increase) |

Notice that for simplicity the government is assumed to receive and pay such a billing within the terminating period of the contract.

Incentive profit based on system performance is handled the same way as cost. Thus the entries are

Cash in period t" and state-of-nature s due to contract c $\sum_{i=1}^{B} {}_R\gamma_{is}({}_c z_{is} - \bar{z}_{is})$ (increase)

Government Sales Revenue in period t" and state-of-nature s due to contract c $\sum_{i=1}^{B} {}_c\gamma_{is}({}_c z_{is} - {}_c\bar{z}_{is})$ (increase)

Incentive profit based on schedule is also handled in the same manner. Thus the entries are

Cash in period t" and state-of-nature s due to contract c ${}_c\epsilon_s \sum_{t'}^{t''} ({}_c q_{ts} - {}_c\bar{q}_{ts})$ (increase)

Government Sales Revenue in period t" and state-of-nature s due to contract c ${}_c\epsilon_s \sum_{t'}^{t''} ({}_c q_{ts} - {}_c\bar{q}_{ts})$ (increase)

Inventory ($A_{3ts}$)

The contractor's inventory is measured in dollars based on the physical inventory valued by the "last-in-first-out" method. Thus, the current dollar value of inventory is some initial value from period zero plus the value of all material, purchased parts and subcontracted items purchased minus the current market value of all such items used in all periods from zero to the present. It is assumed that no inventory liquidations occur. First, the purely physical inventory equations are repeated from the earlier discussion.

$$\bar{x}_{3ts} = \bar{\bar{x}}_{30s} + \sum_{t=0}^{t-1} (x_{3ts} - y_{4ts})$$

$$\bar{x}_{4ts} = \bar{\bar{x}}_{40s} + \sum_{t=0}^{t-1} (x_{4ts} - y_{3ts})$$

$$x_{5ts} = \bar{\bar{x}}_{50s} + \sum_{t=o}^{t-1} (x_{5ts} - y_{2ts})$$

In dollar value terms this becomes

$$A_{3ts} = A_{330s} + A_{340s} + A_{350s} - \sum_{t=0}^{t-1} \Big\{ w_{3ts}(x_{3ts} - y_{4ts}) +$$
$$w_{4ts}(x_{4ts} - y_{3ts}) + w_{5ts}(x_{5ts} - y_{2ts}) \Big\}$$

Where for notational convenience, the following definition is made

$$A_{0ts} \equiv A_{330s} + A_{340s} + A_{350s}$$

That is, the initial inventory value in dollars ($A_{0ts}$) is the sum of the initial inventory value in dollars of material ($A_{330s}$), purchased parts ($A_{340s}$) and subcontracted parts ($A_{350s}$). The accounting entries by period assume that material, purchased parts and subcontracted parts which physically enter the inventory in period t are processed in t and paid for in period t+1. Thus

| | | |
|---|---|---|
| Inventory in period t and state-of-nature s | $\sum_{i=3}^{5} w_{its} x_{its}$ | (increase) |
| Accounts Payable in period t and state-of-nature s | $\sum_{i-3}^{5} w_{its} x_{its}$ | (increase) |

For the purpose of paying for the material, purchased parts, and subcontracted parts received in period t-1, the entries are

| | | |
|---|---|---|
| Cash in period t and state-of-nature s | $\sum_{i=3}^{5} w_{its} x_{it-1s}$ | (decrease) |
| Accounts Payable in period t and state-of-nature s | $\sum_{i=3}^{5} w_{it-1s} x_{it-1s}$ | (decrease) |

The accounting entries for material, purchased parts, and subcontracted parts which are physically withdrawn for use on a government contract or commercial manufacturing are as follows.

| | | |
|---|---|---|
| Cost of Goods Sold by government contract or commercial product in period period t and state-of-nature s | $\sum_{i=2}^{4} w_{its} \psi'_{its}$ | (increase) |
| Inventory in period t and state-of-nature s | $\sum_{i=2}^{4} w_{its} \psi'_{its}$ | (decrease) |

where $$\psi'_{its} = \sum_{c} {}_{cT}\psi_{its} + \sum_{c} {}_{cT}\psi_{its} + \sum_{c} {}_{cM}\psi_{its} + {}_{\theta}\psi_{its}$$

Plant and Equipment ($A_{4ts}$, $A_{5\,ts}$, $A_{6ts}$)

The physical quantity of contractor owned plant and equipment in time period t and state-of-nature s is as developed earlier

$$k_{its} = (1-\delta)^t \bar{\bar{k}}_{10s} + \sum_{j=1}^{t} (1-\delta)^{t-j} \dot{k}_{1j-1s} \cdot$$

Notice that $k_{1ts}$ is the physical quantity net of depreciation. If the net figure is separated in gross and depreciation on a physical basis, their valuation can be discussed. Gross physical plant and equipment available in period t and state-of-nature s is the net amount available in period t-1 plus any additions to the stock. Thus

$$\text{Gross } k_{1ts} = (1-\delta)^{t-1} k_{10s} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-i} \dot{k}_{1j-1s} + \dot{k}_{1t-1}$$

The physical depreciation is that quantity of plant and equipment available net in period t-1 which "disappears" during the period. Thus

$$\text{Depreciated } k_{1ts} = \delta \left\{ (1-\delta)^{t-1} \bar{\bar{k}}_{10s} + \sum_{j=1}^{t-1} (1-k)^{t-j-1} \dot{}_{1j-1s} \right\}$$

Assume that the contractor evaluates the gross plant and equipment stock at its historical cost. Thus,

$$A_{4ts} = (1-\delta)^{t-1} \bar{\bar{w}}_{k_1 0s} \bar{\bar{k}}_{10} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-1} w_{k_1 j-1s} \dot{k}_{1j-1s} + w_{k_1 t-1s} \dot{k}_{1t-1s}$$

and further assume that the dollar value of physically depreciated plant and equipment is based on historical cost. Thus,

$$A_{5ts} = \delta \left\{ (1-\delta)^{t-i} \bar{\bar{w}}_{k,0s} \bar{\bar{k}}_{10s} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-1} w_{k_1 j-1s} \dot{k}_{1j-s} \right\}$$

Notice that in this paper the value of depreciated plant and equipment is based on physical depreciation at historic cost rather than, for example, a tax-based choice of double declining balance.

The net value on the balance sheet $A_{6ts}$ is the difference of $A_{4ts}$ abd $A_{5ts}$. In equation form, it is

$$A_{6ts} = (1-\delta)^{t} \bar{\bar{w}}_{k_1 0s} \bar{\bar{k}}_{10} + \sum_{j=1}^{t-1} (1-\delta)^{t-j} w_{k_1 j-10} \dot{k}_{1j-1s} + w_{k_1 t-1s} \dot{k}_{1t-1s}$$

The period by period accounting entries for the purchase of new contractor owned plant and equipment delivered and process in period t and paid for in period t+1 are :

| | | |
|---|---|---|
| Plant and Equipment in period t and state-of-nature s | $w_{k_1 ts} k_{1ts}$ | (increase) |
| Accounts Payable in period t and state-of-nature s | $w_{k_1 ts} \dot{k}_{1ts}$ | (increase) |

To record the transaction of paying the invoice for new contractor furnished plant and equipment delivered and processed in period t-1 and paid for in t, the entry is

| | | |
|---|---|---|
| Accounts payable in period t and state-of-nature s | $w_{k_1 t-1s} \dot{k}_{1t-1s}$ | (decrease) |
| Cash in period t and state-of-nature s | $w_{k_1 t-1s} \dot{k}_{1t-1s}$ | (decrease) |

And to record the value of physical decpreciation overall within the contractor

Cost of Goods Sold in period t and state-of-nature s $\quad \delta\left\{(1-\delta)^{t-1}\bar{w}_{k_1 0s} + \sum_{j=1}^{t-1}(1-\delta)^{t-j-1} w_{k_1 j-1s}\dot{k}_{1j-1s}\right\}$ (increase)

Accumulated Depreciation in period t and state-of-nature s $\quad \delta\left\{(1-\delta)^{t-1}\bar{\bar{w}}_{k_1 0s}\bar{\bar{k}}_{10} + \sum_{j=1}^{t-1}(1-\delta)^{t-j-1} w_{k_1 j-1s}\dot{k}_{1j-1s}\right\}$

(increase)

Later in this section, the cost of goods sold account will be subdivided by government contract and commercial products. This will be on the basis of the fraction of total (contractor plus government) plant and equipment used on the contract or in commercial operations.

<u>Accounts Payable</u> ($L_{1ts}$)

The above discussion has already noted entries into accounts payable for inventory and plant and equipment purchase. In addition, the contractor is assumed to hire the services of labor in period t and to pay for those services in period t+1. The accounting entry for this is

Cost of Goods sold by contract and commercial activity in period t and state-of-nature s $\quad \sum_{i=1,2,7,8,11} w_{its}\, x_{its}$ (increase)

Selling and Administrative Expense and Cost of Goods Sold by contract and commercial activity and state-of-nature s $\quad w_{16ts}x_{16ts}$ (increase)

Accounts Payable in period t and state-of-nature s $\quad \sum_{i=1,2,7,8,11,16} w_{its}x_{its}$

(increase)

Also during period t, this labor is paid for its service in period t-1. This is shown by the following entry.

Cash in period t and state-of-nature s $\quad \sum_{i-1,2,7,8,11,16} w_{it-1s}x_{it-1s}$

(decrease)

Accounts Payable in period t and state-of-nature s $\sum_{i=1,2,7,8,11,16} w_{it-1s} x_{it-1s}$ (decrease)

Short-Term Debt ($L_{2ts}$)

Short-term debt represents the contractor's borrowing in the money markets. The contractor is assumed to be able to issue short-term debt (or notes) in each time perod. Rather than introducing the complications of notation needed to keep track of each note and its duration, it is assumed that a time invariant fraction of the notes are due each period. It is also assumed that this fraction is state-of-nature dependent so that possible market risks may be considered. The fraction is denoted $\Phi_{2s}$. If $\ell_{2ts}$ denotes the number of notes outstanding at time t and in state-of-nature s, then just as in the plant and equipment case, the governing physical equation is

$$\ell_{2ts} = (1-\Phi_{2s})^{t} \bar{\bar{\ell}}_{20s} + \sum_{n=1}^{t} (1-\Phi_{2s})^{t-n} \dot{\ell}_{2r-1s}$$

If it is further assumed that the price of a note when sold by the contractor (i.e., net of flotation costs) is $w_{\ell_2 ts}$, Then, in value terms in historical prices the governing equation is

$$L_{2ts} = (1-\Phi_{2s})^{t} \bar{\bar{w}}_{\ell os} \ell_{2os} + \sum_{n=1}^{t} (1-\Phi_{2s})^{t-n} w_{\ell_2 n-1s} \dot{\ell}_{2n-1s}$$

When a quantity of notes are issued in period t and state-of-nature s, the accounting entry is

Short-term Debt in period t and state-of-nature s $w_{\ell_2 ts} \dot{\ell}_{2ts}$ (increase)

Cash in period t and state-of-nature s $w_{\ell_2 ts} \dot{\ell}_{2ts}$ (increase)

The accounting entry for the maturing issues is a magnitude written as

$$\Phi_{2s} L_{2t-1s} = \Phi_{2s} \left\{ (1-\Phi_{2s})^{t-1} \bar{\bar{w}}_{\ell_2 os} \bar{\bar{\ell}}_{2os} + \sum_{n=1}^{t-1} (1-\Phi_{2s})^{t-n-1} w_{\ell_2 n-1s} \ell_{2n-1s} \right\}$$

and entered as follows:

| | | |
|---|---|---|
| Cash in period t and state-of-nature s | $\Phi_{2s} L_{2t-1s}$ | (decrease) |
| Short-term Debt in period t and state-of-nature s | $\Phi_{2s} L_{2t-1s}$ | (decrease) |

<u>Long-Term Debt</u> ($L_{3ts}$)

Long-term debt represents the borrowings in the capital markets. Sometimes these will be called bonds. It is assumed to have the same formal structure as short-term debt. Thus, the physical and value governing equations are

$$\ell_{3ts} = (1-\Phi_{3s})^{t} \bar{\bar{\ell}}_{30s} + \sum_{n=1}^{t} (1-\Phi_{3s})^{t-n} \dot{\ell}_{3,n-1,s}$$

$$L_{3ts} = (1-\Phi_{3s})^{t} \bar{\bar{w}}_{\ell_3 os} \bar{\bar{\ell}}_{30s} + \sum_{n=1}^{t} (1-\Phi_{3s})^{t-n} w_{\ell_3 n-1s} \dot{\ell}_{3n-1s}$$

The accounting entries for bonds issued during period t and state-of-nature s are:

| | | |
|---|---|---|
| Long-term Debt in period t and state-of-nature s | $w_{\ell_2 ts} \dot{\ell}_{3ts}$ | (increase) |
| Cash in period t and state-of-nature s | $w_{\ell_3 ts} \dot{\ell}_{3ts}$ | (increase) |

And for the maturing issues, the entries are:

| | | |
|---|---|---|
| Cash in period t and state-of-nature s | $\Phi_{3s} L_{t-1s}$ | (decrease) |
| Long-term Debt in period t and state of nature s | $\Phi_{3s} L_{t-1s}$ | (decrease) |

where

$$\Phi_{3s} L_{t-1s} = \Phi_{3s} \left\{ (1-\Phi_{3s})^{t-1} \bar{\bar{w}}_{\ell_{3os}} \bar{\bar{\ell}}_{3os} + \sum_{n=1}^{t-1} (1-\Phi_{3s})^{t-n-1} w_{\ell_3 n-1s} \dot{\ell}_{3n-1s} \right\}$$

Capital Stock ($w_{1ts}$)

Capital Stock when issued is assumed to exist throughout the planning horizon. It is assumed that the contractor has the option of issuing stock in each period and state-of-nature. The use of this option is determined in the overall management decision problem. If $\Theta_{1ts}$ denotes the number of shares of stock outstanding in period t and state-of-nature s and $\dot{\Theta}_{1ts}$ the number of shares issued, then the equation for the numbers of outstanding shares is

$$\Theta_{1ts} = \bar{\bar{\Theta}}_{10s} + \sum_{j=o}^{t-1} \dot{\Theta}_{1js}$$

If the price of a share of newly issued stock net of underwriting expenses is $w_{\Theta_1 ts}$ then the book value of these issues is

$$w_{1ts} = \bar{\bar{w}}_{\Theta_1 os} \bar{\bar{\Theta}}_{10s} + \sum_{j=0}^{t-1} w_{\Theta_1 js} \dot{\Theta}_{1js} \qquad t = 1, 2, \ldots, T$$

The accounting entries for issuing of new capital stock are

| | | |
|---|---|---|
| Capital Stock in period t and state-of-nature s | $w_{\Theta_1 ts} \dot{\Theta}_{1ts}$ | (increase) |
| Cash in period t and state-of-nature s | $w_{\Theta_1 ts} \dot{\Theta}_{1ts}$ | (increase) |

Retained Earnings

The retained earnings of the contractor are explained on a period basis earlier in the discussion of the Finance Submodel. Here the balance sheet entry of accumulated retained earnings is considered. As discussed, the basic equation is

$$W_{2ts} = W_{2t-1s} + EAIT_{t-1s} - D_{t-1s}$$

Thus, the accumulated level is

$$W_{2ts} = \bar{\bar{W}}_{20s} + \sum_{t=0}^{t-1} (EAIT_{ts} - D_{ts}) \qquad t = 1, \ldots, T$$

Debt-Interest Expense $(I_{7ts})$

Debt interest expenses are those associated with the outstanding short and long term issues. Assume that each note or bond issued in period t and state-of-nature s states that c dollars will be paid per period or that issue. Specifically, let $c_{2ts}$ and $c_{3ts}$ denote the dollar payments on notes and bonds respectively. Thus for the issues outstanding, the magnitude is

$$(SHORT)\ I_{7ts} = (1-\Phi_{2s})^{t}\ \bar{\bar{c}}_{2os}\ \bar{\bar{\ell}}_{20s} + \sum_{n=1}^{t} (1-\Phi_{2s})^{t-n} c_{2n-1s}\ \dot{\ell}_{2n-1s}$$

$$(LONG)I_{7ts} = (1-\Phi_{3s})^{t}\ \bar{\bar{c}}_{30s}\ \bar{\bar{\ell}}_{30s} + \sum_{n=1}^{t} (1-\Phi_{3s})^{t-n} c_{3n-1s}\ \dot{\ell}_{3n-1s}$$

and

$$I_{7ts} = (SHORT)I_{7ts} + (LONG)I_{7ts}$$

The accounting entries are

| | | |
|---|---|---|
| Debt Interest expense in period t and state-of-nature s | $I_{7ts}$ | (increase) |
| Cash in period t and state-of-nature s | $I_{7ts}$ | (decrease) |

Income Tax Expense $(I_{8ts})$

Income taxes in period t and state-of-nature s are assumed to be a fixed proportion $(r_{ts})$ of taxable income which in general is earnings before interest and taxes minus interest expenses. In equation form this is

$$I_{8ts} = r_{ts}(EBIT_{ts} - I_{7ts})$$

This assumes that the accounting rules for tax purposes, annual reports, and management reports are the same. The accounting entries are

| | | |
|---|---|---|
| Income Tax Expense in period t and state-of-nature s | $I_{8ts}$ | (increase) |
| Cash in period t and state-of-nature s | $I_{8ts}$ | (decrease) |

Cost-of-goods Sold ($I_{4ts}$)

In the discussion above, the cost-of-goods sold account was discussed relative to entries for materials, purchased parts and subcontracted parts used on the various contracts and commercial products. Also discussed were entries for plant and equipment depreciation and labor services. In a breakout of these costs there is also an "overhead" charged to each government contract and commercial sales. Assume that the contractor can classify a fraction of the selling and administrative expenses of the corporate headquarters as "allocated" to the various government contracts and commercial sales. This fraction is denoted $\psi_{ts}$ and is time period and state-of-nature dependent. Thus, the entry listed earlier under the discussion of accounts payable can be entered more accurately as

| | | |
|---|---|---|
| Selling and Administrative Expenses in period t and state-of-nature s | $(1-\psi_{ts})w_{16ts}x_{16ts}$ | (increase) |
| Cost-of-goods sold by contract and commercial activity in period t and state-of-nature s | $\psi_{ts}w_{16ts}x_{16ts}$ | (increase) |
| Accounts Payable in period t and state-of-nature s | $w_{16ts}x_{16ts}$ | (increase) |

The next item to be considered is the cost-of-goods sold by individual government contract and commercial production, i.e., the actual or incurred costs. For simplicity in this first paper, it is assumed that government allowable cost concepts and good accounting practice in commercial production as applied to selling and administrative expenses are embodied in the calculation of $\Psi_{ts}$ and all that remains is the allocation to individual contract and commercial production. Notice that the government and industry groups to a large extent determine $\Psi_{ts}$ and it is outside the direct control of the contractor. It is assumed that this allocation occurs by the fraction of plant and equipment used out of the total in use. Recent discussion by the Cost and Accounting Standard Board indicates that this allocation in the future should be in proportion to the total of all costs allocated to the activity. The other rule now in use is by cost-of-goods sold. It is one use of a model such as this to analyze the effect of such rule changes and variations. Thus, as a first approximation, the overhead charges would be:

government contract c in time period t and state-of-nature s

$$B_{1ct} \equiv \left[\frac{{}_cR^k{}_{ts} + {}_cT^k{}_{ts} + {}_cM^k{}_{ts}}{\sum_c {}_cR^k{}_{ts} + \sum_c {}_cT^k{}_{ts} + \sum_c {}_cM^k{}_{ts} + {}_\theta{}^k{}_{ts} + {}_w{}^k{}_{ts}}\right] \Psi_{ts} w_{16ts} x_{16ts}$$

commercial product in time period t and state-of-nature s

$$B_{2\theta ts} \equiv \left[\frac{{}_\theta{}^k{}_{ts}}{\sum_c {}_cR^k{}_{ts} + \sum_c {}_cT^k{}_{ts} + \sum_c {}_cM^k{}_{ts} + {}_\theta{}^k{}_{ts} + {}_w{}^k{}_{ts}}\right] \Psi_{ts} w_{16ts} x_{16ts}$$

But the overhead charge to inventory warehouse operations must be reallocated to contracts and commercial product. Assume that this reallocation is done by the fraction of the total value of material, purchased parts, and subcontracted parts used in a period that is used on a specific contract or commercial product. Thus, Inventory-warehouse reallocation of overhead to government contract c in time period t and state-of-nature s

$$B_{3cts} \equiv \left[\frac{{}_{w}k_{ts}}{\sum_{c} {}_{cR}k_{ts} + \sum_{c} {}_{cT}k_{ts} + \sum_{c} {}_{cM}k_{ts} + {}_{\theta}k_{ts} + {}_{w}k_{ts}}\right]\left[\frac{\sum_{j=2}^{4} w_{jts}\left({}_{cR}y_{jts} + {}_{cT}y_{jts} + {}_{cM}y_{jts}\right)}{\sum_{j=2}^{4} w_{jts}y_{jts}}\right] w_{16ts}x_{16ts}$$

Inventory-warehouse reallocation of overhead to the commercial product in time period t and state-of-nature s

$$B_{4ts} \equiv \left[\frac{{}_{w}k_{ts}}{\sum_{c} {}_{cR}k_{ts} + \sum_{c} {}_{cT}k_{ts} + \sum_{c} {}_{cM}k_{ts} + {}_{\theta}k_{ts} + {}_{w}k_{ts}}\right]\left[\frac{\sum_{j=2}^{4} w_{jts}\,{}_{\theta}y_{jts}}{\sum_{j=2}^{4} w_{jts}y_{jts}}\right] \psi_{ts}w_{16ts}x_{16ts}$$

The second order overhead charges are then

| | |
|---|---|
| Government contract c in time period t and state-of-nature s | $B_{1cts} + B_{3cts}$ |
| Commercial product in time period t and state-of-nature s | $B_{2\theta ts} + B_{4\theta ts}$ |

In addition, the costs of operating the inventory-warehouse activity must be allocated. The labor costs of operation in period t and state-of-nature s are

Government contract c in time period t

and state-of-nature s

$$B_{5cts} \equiv \left[ \frac{\sum_{j=2}^{4} w_{jts} \left( cR^{y}_{jts} + cT^{y}_{jts} + cM^{y}_{jts} \right)}{\sum_{j=2}^{4} w_{jts} y_{jts}} \right] \left[ w_{7ts} w^{x}_{7ts} + w_{8ts} w^{x}_{8ts} \right]$$

Commercial product in time period t

and state-of-nature s

$$B_{6\theta ts} \quad \left[ \frac{\sum_{j=2}^{4} w_{jts\,\theta} y_{jts}}{\sum_{j=2}^{4} w_{jts} y_{jts}} \right] \left[ w_{7ts} w^{x}_{7ts} + w_{8ts} w^{x}_{8ts} \right]$$

Finally, the total depreciation allocated to inventory-warehouse activities must be reallocated to contract and commercial sales. Assume that depreciation charges are allocated by the quantity of plant and equipment used. Thus the charges are:

Government contract c in time period t

and state-of-nature s

$$B_{7cts} \equiv \left[ \frac{w^{k}_{ts}}{\sum_{c} cR^{k}_{ts} + \sum_{c} cT^{k}_{ts} + \sum_{c} cM^{k}_{ts} + {}_{\theta}^{k}{}_{ts} + w^{k}_{ts}} \right] \left[ \frac{\sum_{j=2}^{4} w_{jts} \left( cR^{y}_{jts} + cT^{y}_{jts} + cM^{y}_{ts} \right)}{\sum_{j=2}^{4} w_{jts} y_{jts}} \right]$$

$$\cdot\, \delta \left\{ (1-\delta)^{t-1} w_{k_1 os} \bar{\bar{k}}_{10s} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-i} w_{k_1 j-1s} \dot{k}_{1j-1s} \right\}$$

Commercial product in time period t

and state-of-nature s

$$B_{8\theta ts} \equiv \left[\frac{w^k_{ts}}{\sum_c {}_cR^k_{ts} + \sum_c {}_cT^k_{ts} + \sum_c {}_cM^k_{ts} + {}_\theta{}^k_{ts} + {}_w{}^k_{ts}}\right]\left[\frac{\sum_{j=2}^{4} w_{jts\theta}\, y_{jts}}{\sum_{j=2}^{4} w_{jts}\, y_{jys}}\right]$$

$$\cdot \left\{(1-\delta)^{t-1} \bar{w}_{k_1 os}\, \bar{\bar{k}}^{t-1}_{0s} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-1} w_{k_1 j-1s}\, \dot{k}_{1j-1s}\right\}$$

So overall the charges are

Government contract c in time period t and state-of-nature s

$$B_{1cts} + B_{3cts} + B_{5cts} + B_{7cts}$$

Commercial product in time period t. and state-of-nature s

$$B_{2\theta ts} + B_{4\theta ts} + B_{6\theta ts} + B_{8\theta ts}$$

Now consider the labor costs in a given time period and state-of nature s on a gonverment contract. With respect to research and development activities, the quantity of contractor supplied engineering labor used is ${}_{cR}x_{lts}$. Thus, the dollar cost of this is $w_{lts}\, {}_{cR}x_{lts}$. With respect to test and evaluation activities, the contractor and the government both supply engineering labor which, in turn, is allocated to the various ongoing contracts. The cost of all contractor supplied engineering labor in test and evaluation is $w_{lts}\, {}_{T}x_{lts}$. The fraction of this that is allocated to contract c is assumed to be the same as the fraction of total contractor and government supplied labor used on all contracts that is used on contract c. Thus, the cost is

$$\left[\frac{{}_cT^x{}_{13ts}}{\sum\limits_c {}_cT^x{}_{13ts}}\right] w_{1ts}\, T^x{}_{1ts}.$$

The cost of engineering labor as far as the contractor is concerned on contract c is then

$$w_{1ts}\left\{ {}_cR^x{}_{1ts} + \left[\frac{{}_cT^x{}_{13ts}}{\sum\limits_c {}_cT^x{}_{13ts}}\right] T^x{}_{1ts}\right\}$$

Since engineering support labor is utilized and supplied in a like manner, the contract c cost for it is

$$w_{2ts}\left\{ {}_cR^x{}_{2ts} + \left[\frac{{}_cT^x{}_{14ts}}{\sum\limits_c {}_cT^x{}_{14ts}}\right] T^x{}_{2ts}\right\}$$

System operators are analogous in use and supply to the test and evaluation part of the engineering labor cost calculation. Thus, the system operator's contract c cost is

$$w_{11ts}\left[\frac{{}_cT^x{}_{15ts}}{\sum\limits_c {}_cT^x{}_{15ts}}\right] x_{11ts}$$

Administrative labor is used in all the contract phases so the cost of this can be computed as

$$w_{7ts}\left({}_cR^x{}_{7ts} + {}_cT^x{}_{7ts} + {}_cM^x{}_{7ts}\right).$$

In addition, it is used in the central warehouse-inventory operation. The cost of this must be reallocated in turn to the users of its services. This is included in the term $B_{5cts}$ discussed earlier. Finally, the manufacturing labor that is directly used is costed at

$$w_{8ts}\, {}_cM^x{}_{8ts}.$$

The reallocation of manufacturing labor used in warehouse-inventory operations is contained in the term $B_{5cts}$ discussed earlier.

The cost of material, purchased parts, and subcontracted parts used on contract c is

$$\sum_{j=2}^{4} w_{jts}\left({}_{c}R^{y}{}_{jts} + {}_{c}T^{y}{}_{jts} + {}_{c}M^{y}{}_{jts}\right)$$

Finally, there is the allocation of total depreciation to the activities of research and development, test and evaluation, and manufacturing on a specific contract. Assume, as before, this is done in proportion to the utilization of total plant and equipment on the contract's activities. Thus

$$B_{9cts} \equiv \left[\frac{{}_{c}R^{k}{}_{ts} + {}_{c}T^{k}{}_{ts} + {}_{c}M^{k}{}_{ts}}{\sum_{c} {}_{c}R^{k}{}_{ts} + \sum_{c} {}_{c}T^{k}{}_{ts} + \sum_{c} {}_{c}M^{k}{}_{ts} + {}_{\theta}{}^{k}{}_{ts} + {}_{w}{}^{k}{}_{ts}}\right]$$

$$\cdot \delta \left\{(1-\delta)^{t-1}\, \bar{\bar{w}}_{k_1 os}\, \bar{\bar{k}}_{10s} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-1}\, w_{k_1 j-1s}\, k_{1j-1s}\right\}$$

for government contracts and

$$B_{10\theta ts} \equiv \left[\frac{{}_{\theta}{}^{k}{}_{ts}}{\sum_{c} {}_{c}R^{k}{}_{ts} + \sum_{c} {}_{c}T^{k}{}_{ts} + \sum_{c} {}_{c}M^{k}{}_{ts} + {}_{\theta}{}^{k}{}_{ts} + {}_{w}{}^{k}{}_{ts}}\right]$$

$$\cdot \delta \left\{(1-\delta)^{t-1}\, \bar{\bar{w}}_{k_1 os}\, \bar{\bar{k}}_{10s} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-1}\, w_{k_1 j-1s}\, k_{1j-1s}\right\}$$

for commercial products.

Overall, then, the measured actual (or incurred) costs for each government contract and commercial production are:

Government contract c in time period t

and state-of-nature s

$$
{}_{c}C_{ts} = w_{1ts}\left\{ {}_{c}R^{x}{}_{1ts} + \left[\frac{{}_{c}T^{x}{}_{13ts}}{\sum_{c} {}_{c}T^{x}{}_{13ts}}\right] T^{x}{}_{1ts} \right\} +
$$

$$
w_{2ts}\left\{ {}_{c}R^{x}{}_{2ts} + \left[\frac{{}_{c}T^{x}{}_{14ts}}{\sum_{c} {}_{c}T^{x}{}_{14ts}}\right] T^{x}{}_{2ts} \right\} +
$$

$$
w_{11ts}\left[\frac{{}_{c}T^{x}{}_{15ts}}{\sum_{c} {}_{c}T^{x}{}_{15ts}}\right] x_{11ts} + w_{7ts}\left( {}_{c}R^{x}{}_{7ts} + {}_{c}T^{x}{}_{7ts} + {}_{c}M^{x}{}_{7ts} \right) +
$$

$$
w_{8ts}\, {}_{c}M^{x}{}_{8ts} + \sum_{j=2}^{4} w_{jts}\left( {}_{c}R^{y}{}_{jts} + {}_{c}T^{y}{}_{jts} + {}_{c}M^{y}{}_{jts} \right) + B_{9cts}
$$

let $\bar{D}_{cts}$ denote the first six terms, i.e., direct labor and materials.

Commercial product in time period t

and state-of-nature s

$$
{}_{\theta}C_{ts} = w_{7ts}\, {}_{\theta}M^{x}{}_{7ts} + w_{8ts}\, {}_{\theta}M^{x}{}_{8ts} + \sum_{j=2}^{4} w_{jts} + B_{10\theta ts}
$$

let $\bar{D}_{\theta ts}$ denote the first three terms, i.e., direct labor and material

Finally, to put it all in one place, the cost-of-goods sold on government contracts in period t and state-of-nature s is the above, plus $B_{1cts} + B_{3cts} + B_{5cts} + B_{7cts}$. And commercial product cost-of-goods sold in period t and state-of-nature s is the above, plus $B_{2\theta ts} + B_{4\theta ts} + B_{6\theta ts} + B_{6\theta ts} + B_{8\theta ts}$. By summing over the contracts from the government and the commercial product, the general entries discussed earlier are obtained. Thus, the purpose of this discussion has been to compute contract costs so that incentive profits may be computed on the contract, as well as indicating the complexity of overhead computation and the interlinkages within the firm created by such calculations.

Dividends ($D_{ts}$)

Dividends are assumed to be decided upon, declared, and paid within a period. Thus, the entries are

| | | |
|---|---|---|
| Dividends in time period t and state-of-nature s | $D_{ts}$ | (increase) |
| Cash in time period t and state-of-nature s | $D_{ts}$ | (decrease) |

Selling and Administrative Expenses ($I_{6ts}$), Accounts Receivable ($A_{2ts}$), Cash ($A_{1ts}$)

These accounts have been discussed as necessary in the preceding accounts discussion. Detailing them separately would add nothing to the discussion, so this will not be done. The T-accounts shown as Figures II-8, II-9, II-10, II-11, II-12, II-13, II-14, II-15, and II-16 reproduce the entries in one place for convenience in "seeing" the system as a whole. The time period and state-of-nature are generally undecided. In fact, there exists such a set of accounts for each of the period (zero to T) and in each state-of-natures s (one to S).

| CASH | |
|---|---|
| ${}_\theta P_{t-1,s}\ {}_\theta q_{t-1,s}$ | $w_{k\,t-1s}\dot{k}_{it-1s}$ |
| $\sum\limits_{\substack{\text{ending}\\ C}} \left[ \sum\limits_{t=t'}^{t''-1} \left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum\limits_{t=t'}^{t''} {}_cC_{ts}}\right] + \left(\Pi_{cs} - \sum\limits_{t=t'}^{t''-1}\left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum\limits_{t-t'}^{t''}{}_cC_{ts}}\right]\right)\right]$ | $\sum\limits_{i=1,2,7,8,11,16} w_{it-1s}x_{it-1s}$ |
| $\sum\limits_{\substack{\text{ongoing}\\ C}} \beta_{cs}\ {}_cC_{t-1,s}$ | $\phi_{2s}\left\{(1-\phi_{2s})^{t-1}\bar{\bar{w}}_{\ell_2 os}\bar{\bar{\ell}}_{2os} + \sum\limits_{n=1}^{t-1}(1-\phi_{2s})^{t-n-1} w_{\ell_2 n-1s}\dot{\ell}_{2n-1s}\right\}$ |
| $\sum\limits_{\substack{\text{ending}\\ C}}\left\{(1-\beta_{cs})\sum\limits_{t=t'}^{t''-1} {}_cC_{ts} + {}_cC_{t''s}\right\}$ | $\phi_{3s}\left\{(1-\phi_{3s})^{t-1}\bar{\bar{w}}_{\ell_3 os}\bar{\bar{\ell}}_{3os} + \sum\limits_{n=1}^{t-1}(1-\phi_{3s})^{t-n-1} w_{\ell_3 n-1s}\dot{\ell}_{3n-1s}\right\}$ |
| $\sum\limits_{\substack{\text{ending}\\ C}}\left\{{}_cb_s\left({}_c\bar{C}_s - \sum\limits_{t=t'}^{t''}{}_cC_{ts}\right)\right\}$ | $(1-\phi_{2s})^{t}\bar{\bar{c}}_{2os}\bar{\bar{\ell}}_{2os} + \sum\limits_{n=1}^{t}(1-\phi_{2s})^{t-n} c_{2n-1s}\dot{\ell}_{2n-1s} + (1-\phi_{3s})^{t}\bar{\bar{c}}_{30s}\bar{\bar{\ell}}_{30s} + \sum\limits_{n=1}^{t}(1-\phi_{3s})^{t-n} c_{3n-1s}\dot{\ell}_{3n-1s} \equiv I_{7ts}$ |
| $\sum\limits_{\substack{\text{ending}\\ C}}\left(\sum\limits_{i=1}^{B}{}_c\gamma_{is}\left\{{}_cz_{is} - {}_c\bar{z}_{is}\right\}\right)$ | $r_{ts}(EBIT_{ts} - I_{7ts})$ |
| | $D_{ts}$ |
| $\sum\limits_{\substack{\text{ending}\\ C}}\left\{{}_c\varepsilon_s \sum\limits_{t=t'}^{t''}\left({}_cq_{ts} - {}_c\bar{q}_{ts}\right)\right\}$ | $\sum\limits_{i=3}^{5} w_{it-1s}x_{it-1s}$ |
| $w_{\ell_2 ts}\dot{\ell}_{2ts}$ | |
| $w_{\ell_3 ts}\dot{\ell}_{3ts}$ | |
| $w_{\sigma_1 ts}\dot{\sigma}_{1ts}$ | |

FIGURE II-8

TRANSACTIONS IN

CASH ACCOUNT FOR PERIOD t

AND STATE-OF-NATURE s

ACCOUNTS RECEIVABLE

| | |
|---|---|
| ${}_\theta P_{ts}\ {}_\theta q_{ts}$ | ${}_\theta P_{t-1,s}\ {}_\theta q_{t-1,s}$ |
| $\sum_{\substack{\text{ongoing} \\ c}} \left[\dfrac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right] \Pi_{cs}$ | $\sum_{\substack{\text{ending} \\ c}} \sum_{t=t'}^{t''-1} \left[\dfrac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]$ |
| $\sum_{\substack{\text{ongoing} \\ c}} {}_cC_{ts}$ | $\sum_{\substack{\text{ongoing} \\ c}} \beta_{cs}\ {}_cC_{t-1,s}$ |
| | $\sum_{\substack{\text{ending} \\ c}} \left\{(1-\beta_{cs}) \sum_{t=t'}^{t''-1} {}_cC_{ts}\right\}$ |

INVENTORY

| | |
|---|---|
| $\sum_{i=3}^{5} w_{its} x_{its}$ | $\sum_{i=2}^{4} \left\{ w_{its} \left( \sum_{\substack{\text{ongoing} \\ c}} {}_cR^y_{its} + \sum_{\substack{\text{ongoing} \\ c}} {}_cT^y_{its} + \sum_{\substack{\text{ongoing} \\ c}} {}_cM^y_{its} + {}_\theta y_{its} \right) \right\}$ |

FIGURE II-9

TRANSACTIONS IN

ACCOUNTS RECEIVABLE AND INVENTORY

ACCOUNTS FOR PERIOD t AND

STATE-OF-NATURE s

PLANT AND EQUIPMENT

| | |
|---|---|
| $w_{k_1 ts}\dot{k}_{1ts}$ | |

ACCUMULATED DECRECIATION

| | |
|---|---|
| $\delta \left\{(1-\delta)^{t-1}\bar{\bar{w}}_{k_1 o}\bar{\bar{k}}_{10}+\sum_{j=1}^{t-1}(1-\delta)^{t-j-1} w_{k_1 j-1s}\dot{k}_{1j-1s}\right\}$ | |

FIGURE II-10

TRANSATIONS IN

PLANT AND EQUIPMENT AND ACCUMULATED DEPRECIATION

ACCOUNTS FOR PERIOD t AND

STATE-OF-NATURE s

ACCOUNTS PAYABLE

| | |
|---|---|
| $\sum_{i=3}^{5} w_{its} x_{its}$ | $w_{k_1 t-1s} \dot{k}_{t-1s}$ |
| $w_{k_1 ts} \dot{k}_{1ts}$ | $\sum_{1=1,2,7,8,11,16} w_{it-1s} x_{it-1s}$ |
| $\sum_{i=1,2,7,8,11,16} w_{its} x_{its}$ | $\sum_{i=3}^{5} w_{it-1s} w_{it-1s}$ |

SHORT TERM DEBT

| | |
|---|---|
| $w_{\ell_2 ts} \dot{\ell}_{2ts}$ | $\phi_{2s} \left\{ (1-\phi_{2s})^{t-1} \bar{\bar{w}}_{\ell_2 os} \bar{\bar{\ell}}_{2os} + \sum_{n=1}^{t-1} (1-\phi_{2s})^{t-n-1} w_{\ell_x n-1s} \dot{\ell}_{2n-s} \right\}$ |

LONG TERM DEBT

| | |
|---|---|
| $w_{\ell_3 ts} \dot{\ell}_{3ts}$ | $\phi_{3s} \left\{ (1-\phi_{3s})^{t-1} \bar{\bar{w}}_{\ell_3 os} \dot{\ell}_{2os} + \sum_{n=1}^{t-1} (1-\phi_{3s})^{t-n-1} w_{\ell_2 n-1s} \dot{\ell}_{2n-1s} \right\}$ |

FIGURE II-11

TRANSACTIONS IN

ACCOUNTS PAYABLE, SHORT TERM DEBT AND LONG TERM DEBT

ACCOUNTS FOR PERIOD t AND

STATE-OF-NATURE s

CAPITAL STOCK

| | |
|---|---|
| $W_{\theta_1 ts}\dot{\sigma}_{1ts}$ | |

RETAINED EARNINGS

| | |
|---|---|
| $D_{t-1,s}$ | $W_{2,t-1,s}$ |
| | $EAIT_{t-1,s}$ |

FIGURE II-12

TRANSATIONS IN

CAPITAL STOCK AND RETAINED EARNINGS

ACCOUNTS FOR PERIOD t AND

STATE-OF-NATURE s

COMMERCIAL SALES REVENUE

$$\theta^{p}{}_{ts}\ \theta^{q}{}_{ts}$$

GOVERNMENT SALES REVENUE

$$\sum_{\substack{\text{ongoing}\\ c}} \left[\frac{\beta_{cs}\ {}_{c}C_{ts}}{\sum\limits_{t=t'}^{t''} {}_{c}C_{ts}}\right]\Pi_{cs}$$

$$\sum_{\substack{\text{ending}\\ c}} \left(\Pi_{cs} - \sum_{t=t'}^{t''-1}\left[\frac{\beta_{cs}\ {}_{c}C_{ts}}{\sum\limits_{t=t'}^{t''} {}_{c}C_{ts}}\right]\right)$$

$$\sum_{\substack{\text{ongoing}\\ c}} {}_{c}C_{ts}$$

$$\sum_{\substack{\text{ending}\\ c}} {}_{c}C_{t''s}$$

$$\sum_{\substack{\text{ending}\\ c}} \left\{ {}_{c}b_{s}\left({}_{c}\bar{C}_{s} - \sum_{t=t'}^{t''} {}_{c}C_{ts}\right)\right\}$$

$$\sum_{\substack{\text{ending}\\ c}} \left(\sum_{i=1}^{B} {}_{c}\gamma_{is}\left\{{}_{c}z_{ts} - {}_{c}\bar{z}_{ts}\right\}\right)$$

$$\sum_{\substack{\text{ending}\\ c}} \left\{ {}_{c}\varepsilon_{s} \sum_{t=t'}^{t''} \left({}_{c}q_{ts} - {}_{c}\bar{q}_{ts}\right)\right\}$$

FIGURE II-13

TRANSACTIONS IN

COMMERCIAL SALES REVENUE AND GOVERNMENT SALES REVENUE

ACCOUNTS FOR PERIOD t AND

STATE- OF-NATURE s

COST OF GOODS SOLD

$$\sum_{i=2}^{4}\left\{w_{its}\left(\sum_{\substack{\text{ongoing}\\ c}} {}_{cR}y_{its}+\sum_{\substack{\text{ongoing}\\ c}} {}_{cT}y_{its} + \sum_{\substack{\text{ongoing}\\ c}} {}_{cM}y_{its}+ {}_{\theta}y_{its}\right)\right\}$$

$$\delta\left\{(1-\delta)^{t-1}\,\bar{\bar{w}}_{k_1 os}\bar{\bar{k}}_{10} + \sum_{j=1}^{t-1}(1-\delta)^{t-j-1}w_{k_1 j-1s}\dot{k}_{1j-1s}\right\}$$

$$\sum_{i=1,2,7,8,11} W_{its}x_{its}$$

$$\psi_{ts}w_{16ts}x_{16ts}$$

FIGURE II-14

TRANSACTIONS IN

COST-OF-GOODS SOLD ACCOUNT

FOR PERIOD t AND

STATE-OF-NATURE s

SELLING AND ADMINISTRATIVE EXPENSE

| | |
|---|---|
| $(1-\psi_{ts})w_{16ts}x_{16ts}$ | |

DEBT INTEREST EXPENSE

| | |
|---|---|
| $(1-\phi_{2s})^{t}\bar{\bar{c}}_{20s}\bar{\bar{\ell}}_{20s}+\sum_{n=1}^{t}(1-\phi_{2s})^{t-n}C_{2n-1s}\dot{\ell}_{2n-1s}$ $+(1-\phi_{3s})^{t}\bar{\bar{c}}_{30s}\bar{\bar{\ell}}_{30s}+\sum_{n=1}^{t}(1-\phi_{3s})^{t-n}C_{3n-1s}\dot{\ell}_{3n-1s}$ | |

FIGURE II-15

TRANSACTIONS IN

SELLING AND ADMINISTRATIVE EXPENSE AND DEBT INTEREST EXPENSE

ACCOUNTS FOR PERIOD t AND

STATE-OF-NATURE s

INCOME TAX EXPENSE

| | |
|---|---|
| $r_{ts}(EBIT_{ts}-I_{7ts})$ | |

CASH DIVIDENDS

| | |
|---|---|
| $D_{ts}$ | |

FIGURE II-16

TRANSACTIONS IN

INCOME TAX EXPENSE AND CASH DIVIDENDS

ACCOUNTS FOR PERIOD t AND

STATE-OF-NATURE s

## Flow of Funds

The discussion to this point in the finance submodel has concentrated on the accounting system and the rules for entering transactions. Here all of this information is reduced to a single structural constraint on the contractor's behavior. Since the model under development is cast in flow times, it is natural to develop a flow-of-funds statement for inclusion in the management's overall decision problems. For those unfamiliar with flow-of-funds statements, the following "quick and dirty" exposition is included.

In the abstract, flow-of-funds statements are the differences between balance sheets at the beginning and end of a period. For clarity of exposition, Figure II-17 is included to highlight the assumed timing of transactions and when balance sheets and income statements are "struck". In equation form, the flow-of-funds statement may be computed as

$$\text{Balance sheet at } t: 0 \equiv A_{1ts} + A_{2ts} + A_{3ts} + A_{4ts} - A_{5ts} - L_{1ts} - L_{2ts} - L_{3ts} - W_{1ts} + W_{2ts}$$

$$\text{Balance sheet at } t-1: 0 \equiv A_{1t-1} + A_{2t-1} + A_{3t-1} + A_{4t-1} + A_{5t-1} - L_{1t-1s} - L_{2t-1s} - L_{3t-1s} - W_{1t-1s} - W_{2t-1s}$$

with a difference or flow-of-funds "statement" as

$$\begin{aligned} 0 \equiv\ & (A_{1ts} - A_{1t-1s}) + (A_{2ts} - A_{2t-1s}) + (A_{3ts} - A_{3t-1s}) + (A_{4ts} - A_{4t-1s}) + (A_{5t-1s} - A_{5ts}) \\ & + (L_{1t-1s} - L_{1ts}) + (L_{2t-1s} - L_{2ts}) + (L_{3t-1s} - L_{3ts}) + (W_{1t-1s} - W_{1ts}) + (W_{2t-1s} - W_{2ts}) \end{aligned}$$

In the more usual accounting world this statement would be in terms of sources and uses. However, since any term could be either one, this is not done here for the generic case.

Referring now to this model, funds will be defined as cash. Thus, the generic flow-of-funds statement is of the following form which also includes for clarity, the equation.

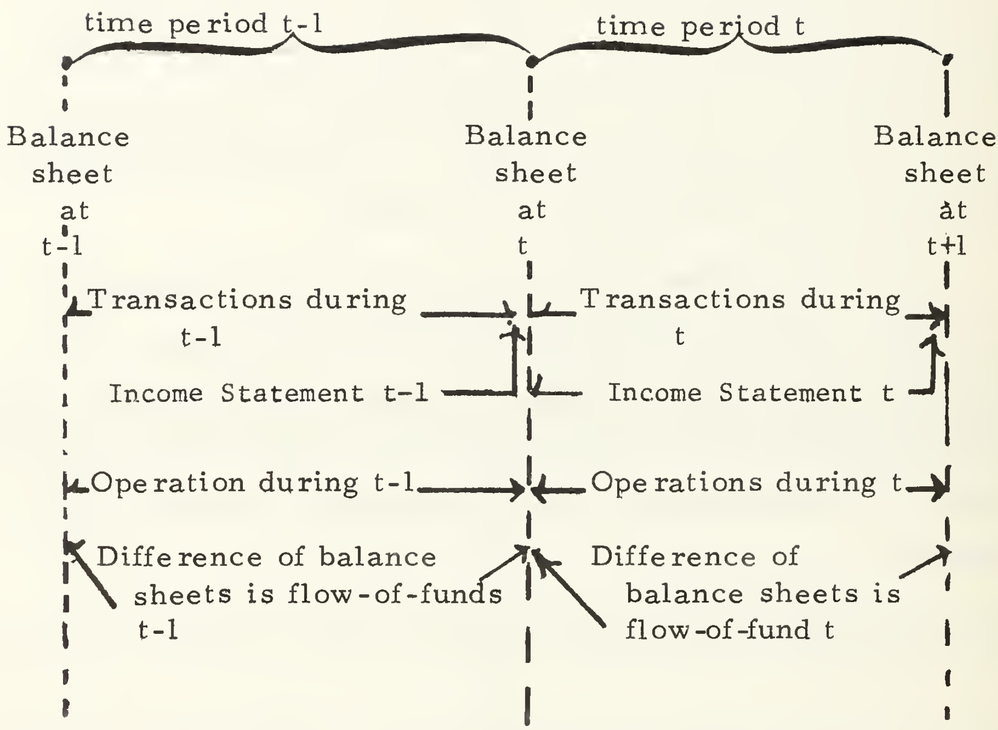


FIGURE II-17

ACCOUNTING TIME PHASING

$$W_{2ts} = W_{2t-1s} + EAIT_{t-1s} - D_{t-1s}.$$

$$A_{1ts} = A_{1t-1s} + (A_{2t-1s} - A_{2ts}) + (A_{3t-1s} - A_{3ts}) + (A_{4t-1s} - A_{4ts})$$

$$+ (A_{5ts} - A_{5t-1s}) + (L_{1ts} - L_{1t-1s}) + (L_{2ts} - L_{2t-1s}) + (L_{3ts} - L_{3t-1s})$$

$$+ (W_{1ts} - W_{1t-1s}) + (EAIT_{t-1s} - D_{t-1s})$$

This is just the beginning entry in the cash account. $(A_{1t-1s})$ plus the flow terms equalling the ending entry. Thus, the detailed equation may be reproduced from the cash account shown as Figure II-8. To put this in the same form as the previous equation, it must be solved for $A_{1ts}$. Letting all the difference terms in the above equation be denoted by $\Delta$, then

$$A_{1ts} = A_{1t-1s} + \Delta_{t-1s} = 0$$

Stating from time zero and writing a few time period equations, the general expression for $A_{1ts}$ is shown below.

$$A_{1ts} = \bar{\bar{A}}_{10s} + \sum_{t=0}^{t} \theta p_{t-1s}\, \theta q_{t-1s} + \sum_{t=0}^{ta} \sum_{\text{ongoing } c} \beta_{cs}\, c^{C}{}_{t-1s} + \sum_{\text{ongoing} c} \beta_{cs}\, c^{C}{}_{t-1s}\Big|_{t=t_0}$$

$$+ \sum_{t=t_c}^{td} \sum_{\text{ongoing } c} \beta_{cs}\, c^{C}{}_{t-1s} + \sum_{\text{ongoing } c} \beta_{cs}\, c^{C}{}_{t-1s}\Big|_{t=t_e} + \sum_{t=t_f}^{tq} \sum_{\text{ongoing } c} \beta_{cs}\, c^{C}{}_{t-1s}$$

$$+ \sum_{\text{ongoing } c} \beta_{cs}\, c^{C}{}_{t-1s}\Big|_{t=t_h} + \sum_{t=0}^{t} \Big\{ w_{\ell_2 ts}\, \dot{\ell}_{2ts} + w_{\ell_3 ts}\, \dot{\ell}_{3ts} - w_{O_1 ts}\, \dot{O}_{1ts}$$

$$- w_{k_1 t-1s}\, \dot{k}_{1t-1s} - \sum_{i=1}^{5,7,8,11,16} w_{it-1s}\, x_{it-1s} - \sum_{j=1}^{2} \phi_{js} \Big[ (1-\phi_{js})^{t-1} \bar{\bar{w}}_{\ell_3 cs}\, \bar{\bar{x}}_{30s}$$

Expression for $A_{1ts}$ (cont'd)

$$+ \sum_{n=1}^{t-1} (1-\phi_{js})^{t-n-1} w_{\ell_3 n-1s} \dot{\ell}_{2n-1s} \Big] - \sum_{j=1}^{2} \Big[ (1-\phi_{js})^{t} \bar{\bar{c}}_{jos} \bar{\bar{\ell}}_{jos}$$

$$+ \sum_{n=1}^{t} (1-\phi_{js})^{t} C_{jn-1s} \dot{\ell}_{jn-1s} \Big]\Big\} - \sum_{t=0}^{t} \Big\{ r_{ts}(1-r_{ts}) \Big[ {}_{\theta}p_{ts} \; {}_{\theta}q_{ts}$$

$$- \sum_{t=1}^{5,7,8,11,16} w_{its} x_{its} - \sum_{j=1}^{2} \Big( (1-\phi_{js})^{t} \bar{\bar{c}}_{jos} \bar{\bar{\ell}}_{jos} - C_{jt-1s} \dot{\ell}_{jt-1s} \Big) \Big] \Big\}$$

$$- \sum_{t=0}^{ta} \Big[ r_{ts}(1-r_{ts}) \Big\{ \sum_{\text{ongoing } C} \Big( \Big[ \frac{\beta_{cs} \; {}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}} \Big] \Pi_{cs} + {}_{c}C_{ts} \Big) - \sum_{i=2}^{4} w_{its} \big( {}_{cr}y_{its}$$

$$+ {}_{cT}y_{its} + {}_{cM}y_{its} + {}_{\theta}y_{its} \big) \Big\} \Big] - r_{ts}(1-r_{ts}) \Big\{ \sum_{\text{ongoing } C} \Big( \Big[ \frac{\beta_{cs} \; {}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}} \Big] \Pi_{cs}$$

$$+ {}_{c}C_{ts} \Big) - \sum_{i=2}^{4} w_{its} \big( {}_{CR}y_{its} + {}_{CT}y_{its} + {}_{CM}y_{its} + {}_{\theta}y_{its} \big) \Big\} \Big|_{t=t_b}$$

$$- \sum_{t=t_c}^{t_d} \Big[ r_{ts}(1-r_{ts}) \Big\{ \sum_{\text{ongoing } C} \Big( \Big[ \frac{\beta_{ts} \; {}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}} \Big] \Pi_{cs} + {}_{c}C_{ts} \Big) - \sum_{i=2}^{4} w_{its} \big( {}_{cR}y_{its}$$

$$+ {}_{cT}y_{its} + {}_{cM}y_{its} + {}_{\theta}y_{its} \big\} \Big] - r_{ts}(1-r_{ts}) \Big\{ \sum_{\text{ongoing } C} \Big( \Big[ \frac{\beta_{cs} \; {}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}} \Big] \Pi_{cs}$$

Expression for $A_{1ts}$ (cont'd)

$$+ {}_cC_{ts}\Big) - \sum_{i=2}^{4} w_{its}({}_{CR}y_{its} + {}_{CT}y_{its} + {}_{CM}y_{its} + {}_{\theta}y_{its})\Big\}\Bigg|_{t=t_e}$$

$$- \sum_{t=t_f}^{tq}\Bigg[ r_{ts}(1-r_{ts}) \Bigg\{ \sum_{\text{ongoing } C}\Bigg(\Bigg[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\Bigg] \Pi_{cs} + {}_cC_{ts}\Bigg)$$

$$- \sum_{i=2}^{4} w_{its}({}_{CR}y_{its} + {}_{CT}y_{its} + {}_{CM}y_{its} + {}_{\theta}y_{its})\Bigg\}\Bigg]$$

$$- r_{ts}(1-r_{ts}) \Bigg\{ \sum_{\text{ongoing } C}\Bigg(\Bigg[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\Bigg] \Pi_{cs} + {}_cC_{ts}\Bigg) - \sum_{i=2}^{4} w_{its}({}_{CR}y_{its}$$

$$+ {}_{CT}y_{its} + {}_{CM}y_{its} + {}_{\theta}y_{its})\Bigg\}\Bigg|_{t=t_h} - \sum_{t=0}^{t} D_{ts} + \sum_{\substack{\text{ending } C \\ \text{during } t_b, t_a, t_c}} \Bigg[\Pi_{cs}$$

$$+ (1-\beta_{cs}) \sum_{t=0}^{t''-1} {}_cC_{ts} + {}_cC_{t''s} + {}_cb_s({}_c\bar{C}_s - \sum_{t=t'}^{t''} {}_cC_{ts}) + \sum_{i=1}^{B} {}_c\gamma_{its}\{{}_cz_{is} - {}_c\bar{z}_{is}\}$$

$$+ {}_c\varepsilon_s \sum_{t=t'}^{t''} ({}_cq_{ts} - {}_c\bar{q}_{ts})\Bigg]$$

where:

(i) a negative index number in a term means that term does not appear

(ii) ongoing c means those contracts ongoing during the relevant time interval or period. For convenience of notation up to period t, the interval $0-t_a$ is assumed to have no ending contracts and the same ongoing contracts; the period $t_b$ is assumed to have ending and starting contracts; the interval $t_c-t_d$ to have the same ongoing contracts; the period $t_e$ to have starting and ending contracts; the interval $t_f-t_g$ to have the same ongoing contracts; and period $t_f$(or t) to have starting and ending contracts. As t moves toward T such intervals and periods are continued as needed.

To buy some specifity to the above equation, Table II-8 shows some examples of the equations for the assumed contract-commercial structure shown in Figure II-1.

## Financial Management

Now that the structural constraint on contractor behavior due to the nature of the accounting system has been established, it is possible to discuss the financial management aspects of the contractor behavior. In the flow of funds statement are most of the decision variables previously discussed as either real physical variables or environmental interaction variables. Specifically, the financial management decision variables are the quantity of short term debt to issue, the quantity of long term debt to issue, the quantity of capital sotck to issue, and the amount of retained earnings and dividends to keep and pay respectively. The choice of these quantities and amounts in each time period and each state-of-nature is the

TABLE II-8

TIME PHASED FLOW OF FUNDS STATEMENTS

$0 \leq t \leq t_1$

$$A_{10c} = \bar{\bar{A}}_{10s} + w_{\ell_2 os}\dot{\ell}_{2os} + w_{\ell_3 os}\dot{\ell}_{3os} + w_{\sigma_1 os}\dot{\sigma}_{10s} - \bar{\bar{C}}_{20s}\bar{\bar{\ell}}_{20s}$$

$$- \bar{\bar{C}}_{30s}\bar{\bar{\ell}}_{30s} - r_{os}(1-r_{os})\left\{ \theta P_{cs}\theta q_{os} + \sum_{c=1}^{5}\left[\frac{\beta_{cs}\ {}_cC_{os}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]\Pi_{cs}\right.$$

$$+ \sum_{c=1}^{5} {}_cC_{os} - \sum_{i=2}^{4}\left(w_{ios}\left(\sum_{c=1}^{5} {}_{cR}y_{ios} + \sum_{c=1}^{5} {}_{cT}y_{ios}\right.\right.$$

$$\left.\left. + \sum_{c=1}^{5} {}_{cM}y_{ios} + {}_{\theta}y_{ios}\right)\right) - \sum_{i=1,2,7,8,11} w_{ios}x_{ios}$$

$$- \psi_{02}w_{16os}x_{16os} - (1-\psi_{0s})w_{16os}x_{16os} - \bar{\bar{C}}_{20s}\bar{\bar{\ell}}_{20s}$$

$$\left. - \bar{\bar{C}}_{30s}\bar{\bar{\ell}}_{30s}\right\} - D_{os}$$

$t_1 \leq t \leq t_2$

$$A_{11s} = \bar{\bar{A}}_{10s} + \theta P_{os}\theta q_{os} + \sum_{c=1}^{5}\beta_{cs}\ {}_cC_{os} + \sum_{t=o}^{1} w_{\ell_2 ts}\dot{\ell}_{2ts}$$

$$+ \sum_{t=0}^{1} w_{\ell_3 ts}\dot{\ell}_{3ts} + \sum_{t=0}^{1} w_{\sigma_1 ts}\dot{\sigma}_{1ts} - w_{k_1 os}\dot{k}_{1os}$$

$$- \sum_{i=1,2,7,8,11,16} w_{ios}x_{ios} - \phi_{2s}\left\{\bar{\bar{w}}_{\ell_2 os}\bar{\bar{\ell}}_{2os}\right\}$$

$$- \phi_{3s}\left\{\bar{\bar{w}}_{\ell_3 os}\bar{\bar{\ell}}_{3os}\right\} - \sum_{t=o}^{1}(1-\phi_{2s})^{t}\bar{\bar{C}}_{2os}\bar{\bar{\ell}}_{2os} - C_{2os}\dot{\ell}_{2os}$$

$$- \sum_{t=0}^{1}(1-\phi_{3s})^{t}\bar{\bar{C}}_{3os}\bar{\bar{\ell}}_{3os} - C_{3os}\dot{\ell}_{3os}$$

$$- \sum_{t=0}^{1}\left(r_{ts}(1-r_{ts})\left\{\theta P_{ts}\theta q_{ts} + \sum_{c=1}^{5}\left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]\Pi_{cs}\right.\right.$$

$$+ \sum_{c=1}^{5} {}_cC_{ts} - \sum_{i=2}^{4}\left(w_{its}\left[\sum_{c=1}^{5} {}_{cR}y_{its} + \sum_{c=1}^{5} {}_{cT}y_{its}\right.\right.$$

TABLE II-8 (cont'd)

$$+ \sum_{c=1}^{5} {}_{cM}y_{its} + {}_{\theta}y_{its} \Big]\Big) - \sum_{i=1,2,7,8,11} w_{its}x_{its}$$

$$- \Psi_{ts}w_{16ts}x_{16ts} - (1-\Psi_{ts})w_{16ts}x_{16ts}$$

$$- (1 - \phi_{2s})^{t}\bar{\bar{C}}_{2os}\bar{\bar{\ell}}_{2os} - C_{2os}\dot{\ell}_{2os}$$

$$+ (1 - \phi_{3s})^{t}\bar{\bar{C}}_{3ts}\bar{\bar{\ell}}_{3ts} + C_{3os}\dot{\ell}_{3os}\Big\}\Big) - \sum_{t=0}^{1} D_{ts}$$

$$- \sum_{i=3}^{5} w_{ios}x_{ios}$$

$t_2 \leq t \leq t_3$

$$A_{12s} = \bar{\bar{A}}_{10s} + \sum_{t=0}^{2} {}_{\theta}p_{t-1s}\,{}_{\theta}q_{t-1s} + \sum_{c=1}^{5} \beta_{cs}C_{os} + \sum_{c=1}^{5,13} \beta_{cs}C_{1s}$$

$$+ \sum_{t=0}^{2} w_{\ell_2 ts}\dot{\ell}_{2ts} + \sum_{t=0}^{5} w_{\ell_3 ts}\dot{\ell}_{3ts} + \sum_{t=0}^{2} w_{\sigma_1 ts}\dot{\sigma}_{1ts}$$

$$- \sum_{t=0}^{2} w_{k_1 t-1s}\dot{k}_{1t-1s} - \sum_{t=0}^{2} \sum_{i=1,2,7,8,11,16} w_{it-1s}x_{1t-1s}$$

$$- \sum_{t=0}^{2} \phi_{2s} \Big\{(1 - \phi_{2s})^{t-1}\bar{\bar{w}}_{\ell_2 os}\bar{\bar{\ell}}_{2os} + w_{\ell_2 os}\dot{\ell}_{2os}\Big\}$$

$$- \sum_{t=0}^{2} \phi_{3s}\Big\{(1 - \phi_{3s})^{t-1}\bar{\bar{w}}_{\ell_3 os}\bar{\bar{\ell}}_{3os} + w_{\ell_2 os}\dot{\ell}_{3os}\Big\}$$

$$- \sum_{t=0}^{2} \Big\{(1 - \phi_{2s})^{t}\bar{\bar{c}}_{2os}\bar{\bar{\ell}}_{2os} + \sum_{n=1}^{t} (1 - \phi_{2s})^{t-n}C_{2n-1s}\dot{\ell}_{2n-1s}\Big\}$$

$$- \sum_{t=0}^{2} \Big\{(1 - \phi_{3s})^{t}\bar{\bar{c}}_{3os}\bar{\bar{\ell}}_{3os} + \sum_{n=1}^{t} (1 - \phi_{3s})^{t-n}C_{3n-1s}\dot{\ell}_{3n-1s}\Big\}$$

$$- \sum_{t=0}^{1} \Big[r_{ts}(1 - r_{ts})\Big\{{}_{\theta}p_{ts}\,{}_{\theta}q_{ts} + \sum_{c=1}^{5} \left[\frac{\beta_{cs}\,{}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}}\right]\Pi_{cs}$$

$$+ \sum_{c=1}^{5} {}_cC_{ts} - \sum_{i=2}^{4} \left( w_{its} \left\langle \sum_{c=1}^{5} {}_{cR}y_{its} + \sum_{c=1}^{5} {}_{cT}y_{its} \right.\right.$$

$$\left.\left. + \sum_{c=1}^{5} {}_{cM}y_{its} + {}_{\theta}y_{its} \right\rangle\right) - \sum_{i=1,2,7,8,11} w_{its}x_{its}$$

$$- \psi_{ts} w_{16os} x_{16os} - (1 - \psi_{ts}) w_{16os} x_{16os}$$

$$- (1 - \phi_{2s})^{t=} \bar{\bar{c}}_{20s} \bar{\bar{\ell}}_{20s} - C_{20s} \dot{\ell}_{20s} - (1 - \phi_{3s})^{t=} c_{3ts} \ell_{3ts}$$

$$- C_{30s} \dot{\ell}_{30s} \Big\} - r_{2s}(1 - r_{ts}) \Big\{ {}_{\theta}P_{2s} \; {}_{\theta}q_{ts}$$

$$+ \sum_{c=1}^{5,13} \left[ \frac{\beta_{ts} \; {}_cC_{2s}}{\sum_{t=t'}^{t'} {}_cC_{ts}} \right] \Pi cs + \sum_{i=1}^{5,13} \Big\{ {}_cC_{2s}$$

$$- \sum_{i=1}^{4} w_{i2s} ( {}_{cR}y_{i2s} + {}_{cT}y_{i2s} + {}_{cM}y_{i2s} + {}_{\theta}y_{i2s} ) \Big\}$$

$$- \sum_{i=1,2,7,11} w_{i2s} x_{i2s} - \psi_{2s} \; w_{162s} x_{162s}$$

$$- (1 - \psi_{2s}) w_{162s} x_{162s} - (1 - \phi_{2s})^{2} \bar{\bar{C}}_{20s} \bar{\bar{\ell}}_{20s}$$

$$- C_{21s} \dot{\ell}_{21s} - (1 - \phi_{3s})^{2} \bar{\bar{C}}_{32s} \bar{\bar{\ell}}_{32s} - C_{31s} \dot{\ell}_{31s} \Big\}$$

$$- \sum_{t=0}^{2} D_{ts} - \sum_{t=0}^{2} \sum_{i=3}^{5} w_{it-1s} x_{it-1s}$$

$t_3 \leq t \leq t_4$

$$A_{13s} = \bar{\bar{A}}_{10s} + \sum_{t=0}^{3} {}_{\theta}P_{t-1s} \; {}_{\theta}q_{t-1s} + \sum_{t=0}^{1} \sum_{c=1}^{5} \beta_{cs} \; {}_cC_{t-1s}$$

$$+ \sum_{t=2}^{3} \sum_{c=1}^{5,13} \beta_{cs} \; {}_cC_{t-1s} + \sum_{t=o}^{3} w_{\ell_2 ts} \dot{\ell}_{2ts}$$

TABLE II-8 (cont'd)

$$+ \sum_{t=0}^{3} w_{\ell_3 ts}\dot{\ell}_{3ts} + \sum_{t=0}^{3} w_{\sigma_1 ts}\dot{\sigma}_{1ts} - \sum_{t=0}^{3} w_{k_1 t-1s}\dot{k}_{1t-1s}$$

$$- \sum_{t=0}^{3}\sum_{i=1}^{5,7,8,11,16} w_{it-1s}x_{it-1s} - \sum_{t=0}^{3}\phi_{2s}\Big\{(1-\phi_{2s})^{t-1}\bar{\bar{w}}_{\ell_2 os}\bar{\bar{\ell}}_{2os}$$

$$+ \sum_{n=1}^{t-1}(1-\phi_{2s})^{t-n-1} w_{\ell_2 n-1s}\dot{\ell}_{2n-1s}\Big\} - \sum_{t=0}^{3}\phi_{3s}\Big\{(1-\phi_{3s})^{t-1}\bar{\bar{w}}_{l_3 os}\bar{\bar{l}}_{3os}$$

$$+ \sum_{n=1}^{t-1}(1-\phi_{3s})^{t-n-1} w_{\ell_3 n-1s}\dot{\ell}_{2n-1s}\Big\} - \sum_{t=0}^{3}\Big\{(1-\phi_{2s})^{t}\bar{\bar{c}}_{20s}\bar{\bar{\ell}}_{20s}$$

$$+ \sum_{n=1}^{t}(1-\phi_{2s})^{t-n}C_{2n-1s}\dot{\ell}_{2n-1s} + (1-\phi_{3s})^{t}\bar{\bar{c}}_{3os}\bar{\bar{\ell}}_{3os}$$

$$+ \sum_{n=1}^{t}(1-\phi_{3s})^{t-n}C_{3n-1s}\dot{\ell}_{3n-1s}\Big\}$$

$$- \sum_{t=0}^{3}\Big[r_{ts}(1-r_{ts})\Big\{{}_{\theta}P_{ts}\ {}_{\theta}q_{ts} - \sum_{i=1}^{5,7,8,11} w_{its}x_{its} - w_{16ts}x_{16ts}$$

$$- (1-\phi_{2s})^{t}\bar{\bar{C}}_{2os}\bar{\bar{\ell}}_{2os} - C_{2t-1s}\dot{\ell}_{2t-1s}$$

$$- (1-\phi_{3s})^{t}\bar{\bar{C}}_{3os}\bar{\bar{\ell}}_{3os} - C_{3t-1s}\dot{\ell}_{3t-1s}\Big]$$

$$- \sum_{t=0}^{1}\Big[r_{ts}(1-r_{ts})\Big\{\sum_{c=1}^{5}\Big(\left[\frac{\beta_{cs}\ {}_{c}C_{ts}}{\sum_{t=t'}^{t''}{}_{c}C_{ts}}\right]\Pi cs + {}_{c}C_{ts}$$

$$- \sum_{i=2}^{4} w_{its}\left\langle {}_{cR}y_{its} + {}_{cT}y_{its} + {}_{cM}y_{its} + {}_{\theta}y_{its}\right\rangle\Big)\Big\}\Big]$$

$$- \sum_{t=2}^{3}\Big[r_{ts}(1-r_{ts})\Big\{\sum_{c=1}^{5,13}\Big(\left[\frac{\beta_{cs}\ {}_{c}C_{ts}}{\sum_{t=t'}^{t''}{}_{c}C_{ts}}\right]\Pi cs + {}_{c}C_{ts}$$

$$- \sum_{c=2}^{4} w_{its} \left\langle {}_{cR}y_{its} + {}_{cT}y_{its} + {}_{cM}y_{its} + {}_{\theta}y_{its} \right\rangle \Big) \Big\} \Big]$$

$$- \sum_{t=o}^{3} D_{ts}$$

$t_4 \leq t \leq t_5$

$$A_{14s} = \bar{\bar{A}}_{10c} + \sum_{t=0}^{4} {}_{\theta}p_{t-1s}\ {}_{\theta}q_{t-1s} + \sum_{t=o}^{1} \sum_{c=1}^{5} \beta_{cs}\ {}_{c}C_{t-1s}$$

$$+ \sum_{t=2}^{3} \sum_{c=1}^{5,13} \beta_{cs}\ {}_{c}C_{t-1s} + \sum_{c=1}^{6,13} \beta_{cs}\ {}_{c}C_{3s}$$

$$+ \sum_{t=0}^{4} \Big\{ w_{\ell_2 ts} \dot{\ell}_{2ts} + w_{\ell_3 ts} \dot{\ell}_{3ts} + w_{\sigma_1 ts} \dot{\sigma}_{1ts}$$

$$- w_{k_1 t-1s} \dot{k}_{1t-1s} - \sum_{i=1}^{5,7,8,11,16} w_{it-1s} x_{it-1s} \Big\}$$

$$- \sum_{t=0}^{4} \phi_{2s} \Big\{ (1 - \phi_{2s})^{t-1} \bar{\bar{w}}_{\ell_2 os} \bar{\bar{\ell}}_{20s}$$

$$+ \sum_{n=1}^{t-1} (1 - \phi_{2s})^{t-n-1} w_{\ell_2 n-1s} \dot{\ell}_{2n-1s} \Big\}$$

$$- \sum_{t=0}^{4} \phi_{3s} \Big\{ (1 - \phi_{3s})^{t-1} \bar{\bar{w}}_{\ell_3 os} \bar{\bar{\ell}}_{3os}$$

$$+ \sum_{n=1}^{t-1} (1 - \phi_{3s})^{t-n-1} w_{\ell_3 n-1s} \dot{\ell}_{2n-1s} \Big\}$$

$$- \sum_{t=0}^{4} \sum_{j=1}^{2} \Big\{ (1 - \phi_{js})^{t} \bar{\bar{c}}_{jos} \bar{\bar{\ell}}_{jos}$$

$$+ \sum_{n=1}^{t} (1 - \phi_{js})^{t-n} c_{jn-1s} \dot{\ell}_{jn-1s} \Big\}$$

$$- \sum_{t=0}^{4} \Bigg[ r_{ts}(1-r_{ts}) \Big\{ {}_{\theta}P_{ts\theta}q_{ts} - \sum_{i=1}^{5,7,8,11,16} w_{its}x_{its}$$

$$- \sum_{j=1}^{2} (1-\phi_{js}) \overset{t}{} \bar{\bar{C}}_{jos}\bar{\bar{\ell}}_{jos} - C_{jt-1s}\dot{\ell}_{jt-1s} \Big\} \Bigg]$$

$$- \sum_{t=0}^{1} \Bigg[ r_{ts}(1-r_{ts}) \Big\{ \sum_{c=2}^{5} \Bigg( \left[ \frac{\beta_{cs}\, {}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}} \right] \Pi_{cs} + {}_{c}C_{ts}$$

$$- \sum_{i=2}^{4} w_{its} ( {}_{cR}y_{its} + {}_{cT}y_{its} + {}_{cM}y_{its} + {}_{\theta}y_{its} ) \Bigg) \Big\} \Bigg]$$

$$- \sum_{t=2}^{3} \Bigg[ r_{ts}(1-r_{ts}) \Big\{ \sum_{c=1}^{5,13} \Bigg( \left[ \frac{\beta_{cs}\, {}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}} \right] \Pi_{cs} + {}_{c}C_{ts}$$

$$- \sum_{i=2}^{4} w_{its} ( {}_{cR}y_{its} + {}_{cT}y_{its} + {}_{cM}y_{its} + {}_{\theta}y_{its} ) \Bigg) \Big\} \Bigg]$$

$$- r_{4s}(1-r_{4s}) \Big\{ \sum_{c=1}^{6,13} \Bigg( \left[ \frac{\beta_{cs}\, {}_{c}C_{4s}}{\sum_{t=t'}^{t} {}_{c}C_{ts}} \right] \Pi_{cs} + {}_{c}C_{4s}$$

$$- \sum_{i=2}^{4} w_{i4s} ( {}_{cR}y_{i4s} + {}_{cT}y_{24s} + {}_{cM}y_{i4s} + {}_{\theta}y_{i4s} ) \Bigg) \Big\}$$

$$- \sum_{t=0}^{4} D_{ts}$$

For ease of writing out the remaining equations in the table, the above is is rewritten in the following form.

$$A_{14s} = \bar{\bar{A}}_{los} + \sum_{t=1}^{4} (1) + \sum_{t=0}^{1} \sum_{c=1}^{5} (2) + \sum_{t=2}^{3} \sum_{c=1}^{5,13} (2)$$

$$+ \sum_{c=1}^{6,13} ② \Big|_{t-1=3} + \sum_{t=0}^{4} ③ + \sum_{t=0}^{4} ④ + \sum_{t=0}^{4} ⑤$$

$$+ \sum_{t=0}^{4} \sum_{j=1}^{2} ⑥ - \sum_{t=0}^{4} ⑦ - \sum_{t=0}^{1} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{5} ⑧ \right\} \right]$$

$$- \sum_{t=2}^{3} \left[ r_{ts}(1-r_{ts}) \sum_{c=1}^{5,13} ⑧ \right] - r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{5,13} ⑧ \right\} \Big|_{t=4}$$

$$- \sum_{t=0}^{4} D_{ts}$$

$t_5 \leq t \leq t_6$

$$A_{15s} = \bar{\bar{A}}_{10s} + \sum_{t=0}^{5} ① + \sum_{t=0}^{1} \sum_{c=1}^{5} ② + \sum_{t=2}^{3} \sum_{c=1}^{5,13} ②$$

$$+ \sum_{c=1}^{6,13} ② \Big|_{t-1=3} + \sum_{c=1}^{4,6,13} ② \Big|_{t-1=4} + \sum_{t=0}^{5} ③ + \sum_{t=0}^{5} ④$$

$$+ \sum_{t=0}^{5} ⑤ + \sum_{t=0}^{5} \sum_{j=1}^{2} ⑥ - \sum_{t=0}^{5} ⑦$$

$$- \sum_{t=0}^{1} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{5} ⑧ \right\} \right] - \sum_{t=2}^{3} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{5,13} ⑧ \right\} \right]$$

$$- r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{6,13} ⑧ \right\} \Big|_{t=4} - r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{4,6,13} ⑧ \right\} \Big|_{t=5}$$

$$- \sum_{t=0}^{5} D_{ts} + \sum_{t=0}^{5} \left[ \frac{\beta_{5s} \; {}_5C_{ts}}{\sum_{t=0}^{6} {}_5C_{ts}} \right] + \left( \Pi_{5s} - \sum_{t=0}^{5} \left[ \frac{\beta_{5s} \; {}_5C_{ts}}{\sum_{t=0}^{6} {}_5C_{ts}} \right] \right)$$

$$+ (1-\beta_{5s}) \sum_{t=0}^{5} {}_5C_{ts} + {}_5C_{6s} + {}_5b_s \left( {}_5\bar{C}_s - \sum_{t=0}^{6} {}_5C_{ts} \right)$$

$$+ \sum_{i=1}^{B} {}_5\gamma_{is} \left\{ {}_5z_{is} - {}_5\bar{z}_{is} \right\} + {}_5\theta_s \sum_{t=0}^{6} \left( {}_5q_{ts} - {}_5\bar{q}_{ts} \right)$$

TABLE II-8 (cont'd)

$t_6 \leqq t \leqq t_7$ $\quad A_{16s}$

$$= \bar{\bar{A}}_{10s} + \sum_{t=0}^{6} (1) + \sum_{t=0}^{1} \sum_{c=1}^{5} (2) + \sum_{t=2}^{3} \sum_{c=1}^{5,13} (2)$$

$$+ \sum_{c=1}^{6,13} (2) \Big|_{t=1=3} + \sum_{t=5}^{6} \sum_{c=1}^{4,6,13} (2) + \sum_{t=0}^{6} (3) + \sum_{t=0}^{6} (4)$$

$$+ \sum_{t=0}^{6} (5) + \sum_{t=0}^{6} \sum_{j=1}^{2} (6) - \sum_{t=0}^{6} ()$$

$$- \sum_{t=0}^{1} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{5} (8) \right\} \right] - \sum_{t=2}^{3} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{5,13} (8) \right\} \right]$$

$$- r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{6,13} (8) \right\} \Big|_{t=4} - \sum_{t=5}^{6} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{4,6,13} (8) \right\} \right]$$

$$- \sum_{t=0}^{6} D_{ts} + \sum_{t=0}^{5} \left[ \frac{\beta_{5s}\ {}_5C_{ts}}{\sum_{t=0}^{6} {}_5C_{ts}} \right] \left( F_{5s} - \sum_{t=0}^{5} \left[ \frac{\beta_{5s}\ {}_5C_{ts}}{\sum_{t=0}^{6} {}_5C_{ts}} \right] \right)$$

$$+ (1-\beta_{5s}) \sum_{t=0}^{5} {}_5C_{ts} + {}_5C_{6s} + {}_5b_s ({}_5\bar{C}_s - \sum_{t=0}^{6} {}_5C_{ts})$$

$$+ \sum_{i=1}^{B} {}_5\gamma_{is} \left\{ {}_5z_{is} - {}_5\bar{z}_{is} \right\} + {}_5\epsilon_s \sum_{t=0}^{6} ({}_5q_{ts} - {}_5\bar{q}_{ts})$$

$t_7 \leqq t \leqq t_8$ $\quad A_{17s}$ = same as above except the time index in terms b, f, g, h, i, j, k, o, p is to (t=7).

$t_8 \leqq t \leqq t_9$ $\quad A_{15s}$ = same as above except the time index in terms b, f, g, h, i, j, k, o, p is to (t=8).

$t_9 \leqq t \leqq t_{10}$ $\quad A_{19s}$

$$= \bar{\bar{A}}_{10s} + \sum_{t=0}^{9} (1) + \sum_{t=0}^{1} \sum_{c=1}^{5} (2) + \sum_{t=2}^{3} \sum_{c=1}^{5,13} (2) + \sum_{c=1}^{6,13} (2) \Big|_{t-1=3}$$

$$+ \sum_{t=5}^{8} \sum_{c=1}^{4,6,13} (2) + \sum_{c=1}^{3,6,13} (2) \Big|_{t-1=8} + \sum_{t=0}^{9} (3) + \sum_{t=0}^{9} (4)$$

$$+\sum_{t=0}^{9} 5 + \sum_{t=0}^{9}\sum_{j=1}^{2} 6 - \sum_{t=0}^{9} 7$$

$$-\sum_{t=0}^{1}\left[r_{ts}(1-r_{ts})\left\{\sum_{c=0}^{5} 8\right\}\right] - \sum_{t=2}^{3}\left[r_{ts}(i-r_{ts})\left\{\sum_{c=1}^{5,13} 8\right\}\right]$$

$$-\left. r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{6,13} 8\right\}\right|_{t=4} - \sum_{t=5}^{8}\left[r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{4,6,13} 8\right\}\right]$$

$$- r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{3,6,13} 8\right\} - \sum_{t=0}^{9} D_{ts} + \sum_{c=4}^{5}\left[\Pi_{cs}\right.$$

$$+ (1-\beta_{cs}) \sum_{t=0}^{9} {}_cC_{ts} + {}_cC_{10s} + {}_cb_s({}_c\bar{C}_s - \sum_{t=0}^{16} {}_cC_{ts})$$

$$\left. + \sum_{c=1}^{B} {}_c\gamma_{is}\{{}_cz_{is} - {}_c\bar{z}_{is}\} + {}_c\varepsilon_s \sum_{t=0}^{10} ({}_cq_{ts} - {}_c\bar{q}_{ts})\right]$$

$t_{10} \leq t \leq t_{11}$ $A_{110s}$ = same as the above except the time index in terms b, f, g, h, i, j, k, o, p is to (t=10)

$t_{11} \leq t \leq t_{12}$ $A_{111s}$ = same as the above except the time index in terms b, f, g, h, i, j, k, o, p is to (t=11)

$t_{12} \leq t \leq t_{13}$ $A_{112s}$ = same as the above except the time index in terms b, f, g, h, i, j, k, o, p is to (t=12)

$t_{13} \leq t \leq t_{14}$ $A_{113s} = \bar{\bar{A}}_{10s} + \sum_{t=0}^{13} 1 + \sum_{t=0}^{1}\sum_{c=1}^{5} 2 + \sum_{t=2}^{3}\sum_{c=1}^{5,13} 2 + \left.\sum_{c=1}^{6,13} 2\right|_{t-1=3}$

$$+ \sum_{t=5}^{8}\sum_{c=1}^{4,6,13} 2 + \sum_{t=9}^{12}\sum_{c=1}^{3,6,13} 2 + \left.\sum_{c=1}^{2,6,7,13} 2\right|_{t-1=12} + \sum_{t=0}^{13} 3$$

$$+ \sum_{t=0}^{13} 4 + \sum_{t=0}^{13} 5 + \sum_{t=0}^{13}\sum_{j=1}^{2} 6 - \sum_{t=0}^{13} 7$$

$$- \sum_{t=0}^{1}\left[r_{ts}(1-r_{ts}))\left\{\sum_{c=1}^{5} 8\right\}\right] - \sum_{t=2}^{3}\left[r_{ts}(1-r_{ts})\left\{\sum_{t=1}^{5,13} 8\right\}\right]$$

$$- r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{6,13} 8\right\}\Bigg|_{t=4} - \sum_{t=5}^{8}\left[r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{4,6,13} 8\right\}\right]$$

$$- \sum_{t=9}^{12}\left[r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{3,6,13} 8\right\}\right] - r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{2,6,7,13} 8\right\}\Bigg|_{t=13}$$

$$- \sum_{t=0}^{13} D_{ts} - \sum_{c=3}^{13}\left\{\sum_{t=0}^{13}\left[\frac{-\beta_{cs}\,{}_cC_{ts}}{\sum_{t=0}^{14}{}_cC_{ts}}\right] + \left(\Pi_s - \sum_{t=0}^{13}\left[\frac{\beta_{cs}\,{}_cC_{ts}}{\sum_{t=0}^{14}{}_cC_{ts}}\right]\right)\right.$$

$$+(1-\beta_{cs})\sum_{t=0}^{13}{}_cC_{ts} + {}_cC_{14s} + {}_cb_s\left({}_c\bar{C}_s - \sum_{t=0}^{14}{}_cC_{ts}\right)$$

$$\left. + \sum_{i=1}^{B}{}_c\gamma_{is}\left({}_cz_{is} - {}_c\bar{z}_{is}\right) + {}_c\varepsilon_s \sum_{t=0}^{14}\left({}_cq_{ts} - {}_c\bar{q}_{ts}\right)\right\}$$

$t_{14} \leqq t \leqq t_{15}$ $\qquad A_{114s}$ = same as the above except the time index in terms b, f, g, h, i, j, k, o, p is to (t=14)

$t_{15} \leqq t \leqq t_{16}$

$$A_{115s} = \bar{A}_{10s} + \sum_{t=0}^{15} 1 + \sum_{t=0}^{1}\sum_{c=1}^{5} 2 + \sum_{t=2}^{3}\sum_{c=1}^{5,13} 2 + \sum_{c=1}^{6,13} 2\Bigg|_{t-1=3}$$

$$+ \sum_{t=5}^{8}\sum_{c=1}^{4,6,13} 2 + \sum_{t=9}^{12}\sum_{c=1}^{3,6,13} 2 + \sum_{t=13}^{14}\sum_{c=1}^{2,6,7,13} 2 + \sum_{c=2,6,7} 2\Bigg|_{t-1=14}$$

$$+ \sum_{t=0}^{15}\{3 + 4 + 5\} + \sum_{t=0}^{15}\sum_{j=1}^{2} 6 - \sum_{t=0}^{15} 7$$

$$- \sum_{t=0}^{1}\left[r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{5} 8\right\}\right] - \sum_{t=2}^{3}\left[r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{5,13} 8\right\}\right]$$

$$- r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{6,13} 8\right\}\Bigg|_{t=4} - \sum_{t=5}^{8}\left[r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{4,6,13} 8\right\}\right]$$

$$- \sum_{t=9}^{12}\left[r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{3,6,13} 8\right\}\right] - \sum_{t=13}^{14} r_{ts}(1-r_{ts})\left\{\sum_{c=1}^{2,6,7,13} 8\right\}$$

$$- r_{ts}(1-r_{ts}) \left\{ \sum_{c=2,6,7} 8 \right\} \Big|_{t=15} - \sum_{t=0}^{13} D_{ts}$$

$$+ \sum_{c=1,3}^{5,13} \left[ \sum_{t=t'}^{t''-1} \left[ \frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}} \right] + \Pi_{cs} - \sum_{t=t'}^{t''-1} \left[ \frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}} \right] \right]$$

$$+ \sum_{c=1,3}^{5,13} \left\{ (1-\beta_{cs}) \sum_{t=t'}^{t''-1} {}_cC_{ts} + {}_cC_{t''s} + {}_cb_s \left( {}_c\bar{C}_s - \sum_{t=t'}^{t''} {}_cC_{ts} \right) \right.$$

$$\left. + \sum_{i=1}^{B} {}_c\gamma_{is} \left\{ {}_cz_{is} - {}_c\bar{z}_{is} \right\} \right\} + \sum_{c=1,3}^{5,13} \left\{ {}_c\varepsilon_s \sum_{t=t'}^{t''} \left( {}_cq_{ts} - {}_x\bar{q}_{ts} \right) \right\}$$

$t_{16} \leqq t \leqq t_{17}$ $\quad A_{116s}$ = same as the above except the time index in terms b,f,g,h,i,j,k,o,p is to (t=16)

$t_{17} \leqq t \leqq t_{18}$

$$A_{117s} = \bar{\bar{A}}_{10s} + \sum_{t=o}^{17} 1 + \sum_{t=0}^{1} \sum_{c=1}^{5} 2 + \sum_{t=2}^{3} \sum_{c=1}^{5,13} 2 + \sum_{c=1}^{6,13} 2 \Big|_{t-1=3}$$

$$+ \sum_{t=5}^{8} \sum_{c=1}^{4,6,13} 2 + \sum_{t=9}^{12} \sum_{c=1}^{3,6,13} 2 + \sum_{t=13}^{14} \sum_{c=1}^{2,6,7,13} 2 + \sum_{t=15}^{16} \sum_{c=2,6,7} 2$$

$$+ \sum_{c=6,7,8} 2 \Big|_{t-1=16} + \sum_{t=0}^{17} \{ 3 + 4 + 5 \} - \sum_{t=0}^{17} \sum_{j=1}^{2} 6$$

$$- \sum_{t=o}^{17} 7 - \left[ \sum_{t=0}^{1} r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{5} 8 \right\} \right] - \sum_{t=2}^{3} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{5,13} 8 \right\} \right]$$

$$- r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{6,13} 8 \right\} \Big|_{t=4} - \sum_{t=5}^{8} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{4,6,13} 8 \right\} \right]$$

$$- \sum_{t=9}^{12} \left[ r_{ts}(1-r_{ts}) \sum_{c=1}^{3,6,13} 8 \right] - \sum_{t=13}^{14} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=1}^{2,6,7,13} 8 \right\} \right]$$

$$- \sum_{t=15}^{16} \left[ r_{ts}(1-r_{ts}) \left\{ \sum_{c=2,6,7} 8 \right\} - r_{ts}(1-r_{ts}) \left\{ \sum_{c=6}^{8} 8 \right\} \Big|_{t=17} \right]$$

TABLE II-8 (cont'd)

$$-\sum_{t=0}^{17} D_{ts} + \sum_{c=1}^{5,13}\Big(\Pi_{cs} + (1-\beta_{cs}) \sum_{t=0}^{16} {}_cC_{ts} + {}_cC_{17s}$$

$$+ {}_cb_s({}_c\bar{C}_s - \sum_{c=o}^{17} {}_cC_{ts}) + \sum_{i=1}^{B} {}_c\gamma_{is}\{{}_cz_{is} - {}_c\bar{z}_{is}\}$$

$$+ {}_c\varepsilon_s \sum_{t=0}^{17} ({}_cq_{ts} - {}_c\bar{q}_{ts})\Big)$$

| | |
|---|---|
| $t_{18} \leq t \leq t_{19}$ | $A_{118s}$ = same as the above except the time index in terms b,f,g,h,i,j,k,o,p is to (t=18) |
| $t_{19} \leq t \leq t_{20}$ | $A_{119s}$ = same as the above except the time index in terms b, f, g, h, i, j, k, o, p is to (t=19) |

Since the specificity of the general expression is now apparent. The equation will not be written out but the ongoing and ending contracts will be noted for convenience in writing out any equation of interest.

| | | |
|---|---|---|
| $t_{20} \leq t \leq t_{21}$ | ongoing contracts: 6,7,8,14 | ending contracts: none |
| $t_{21} \leq t \leq t_{22}$ | ongoing contracts: 6,7,8, 14 | ending contracts: none |
| $t_{22} \leq t \leq t_{23}$ | ongoing contracts: 6,7,8,9,14 | ending contracts: none |
| $t_{23} \leq t \leq t_{24}$ | ongoing contracts: 6,7,8,9,14 | ending contracts: none |
| $t_{24} \leq t \leq t_{25}$ | ongoing contracts: 7,8,9,14 | ending contracts: 6 |
| $t_{25} \leq t \leq t_{26}$ | ongoing contracts: 7,8,9 | ending contracts: 14 |
| $t_{26} \leq t \leq t_{27}$ | ongoing contracts: 7,9 | ending contracts: 8 |

TABLE II-8 (cont'd)

| | | |
|---|---|---|
| $t_{27} \leq t \leq t_{28}$ | ongoing contracts : 7, 9 | ending contracts: none |
| $t_{28} \leq t \leq t_{29}$ | ongoing contracts: 7, 9, 10 | ending contracts: none |
| $t_{29} \leq t \leq t_{30}$ | ongoing contracts: 9, 10 | ending contracts: 7 |
| $t_{30} \leq t \leq t_{31}$ | ongoing contracts: 9, 10 | ending contracts: none |
| $t_{31} \leq t \leq t_{32}$ | ongoing contracts: 9, 10 | ending contracts: none |
| $t_{32} \leq t \leq t_{33}$ | ongoing contracts: 9, 10 | ending contracts: none |
| $t_{33} \leq t \leq t_{34}$ | ongoing contracts: 9, 10, 11 | ending contracts: none |
| $t_{34} \leq t \leq t_{35}$ | ongoing contracts: 9, 10, 11 | ending contracts: none |
| $t_{35} \leq t \leq t_{36}$ | ongoing contracts: 9,10,11,12 | ending contracts: none |
| $t_{36} \leq t \leq T$ | ongoing contracts: 9,10,11,12 | ending contracts: none |

For convenience in understanding the above equations, the s the starting and ending periods for each contract is as shown below.

| contract number | starting period (t') | ending period (t") |
|---|---|---|
| 1 | 0 | 16 |
| 2 | 0 | 18 |
| 3 | 0 | 14 |
| 4 | 0 | 10 |

TABLE II-8 (cont'd)

| contract number | starting period (t') | ending period (t") |
|---|---|---|
| 5 | 0 | 6 |
| 6 | 4 | 25 |
| 7 | 13 | 30 |
| 8 | 17 | 27 |
| 9 | 22 | beyond planning horizon |
| 10 | 28 | beyond planning horizon |
| 11 | 33 | beyond planning horizon |
| 12 | 35 | beyond planning horizon |
| 13 | 2 | 16 |
| 14 | 20 | 26 |
| 15 (commerical sales) | 0 | beyond planning horizon |

contractor financial management plan. The values of these variables are determined as part of the management's overall choice problem. This problem is formally stated in section II-R.

## P. The Renegotiation Board Submodel

Each time period the contractor is assumed to "face" a review by the Renegotiation Board. This implies that the contractor has at least one million dollars in government sales in each time period and state-of-nature. In the real world of Board actions and procedures, there are accounting system reviews, time lags in decision making, five year loss carry forwards and the like. Undoubtedly of more importance, the Board has never clarified its measure of profits. In fact, it seems to use different measures for different cases [Burns, 3]. Even with this lack of clarity, it is important to include some measure of Board actions in the model since defense contractors apparently are deterred by the existence of the Board from some actions. In addition to the Board itself, there are reviews by the General Accounting Office, Congressional committees, special DOD committees and the like. Each of these has much the same type of effect on defense contractors even if a bit indirect.

For the first specification of the contractor model, pretax renegotiable profits are a percentage of renegotiable sales and will be used as the measure of profit. By upper bounding the value of this measure, the contractor can plan without evoking a negative action on the part of the Board. This is the Board's deterence capability. The use of a state-of-nature subscript permits alternative deterence effects to be considered in the planning for the purpose of formulating this constraint on decision making. Renegotiable revenue will be discussed first, then renegotiable costs and, finally, the profit measurement and upper bound.

Renegotiable Revenue (Sales)

This is the period revenue from government sales as recognized in the accounting system. For any period and all nonterminating contracts, it would be

$$\sum_c \underbrace{\left[\frac{\beta_{cs}\; {}_cC_{ts}}{\sum_{t'}^{t''} {}_cC_{ts}}\right]\Pi_{cs}}_{\text{recognized normal profit}} + \sum_c \underbrace{{}_cC_{ts}}_{\text{recognized costs}} \equiv E_{its} \qquad t=t',\ldots,t''-1$$

In any period for all terminating contracts, it would be

$$\sum_{\text{Term. } c} \left\{ \underbrace{{}_cb_s \{{}_c\bar{C}_s - \sum_{t'}^{t''} {}_cC_{ts}}_{\text{cost saving incentive}} + \sum_{i=1}^{B} {}_c\gamma_{is} \underbrace{({}_cz_{is} - {}_c\bar{z}_{is})}_{\text{performance incentive}} + {}_c\varepsilon_s \sum_{t'}^{t''} \underbrace{({}_cq_{ts} - {}_c\bar{q}_{ts})}_{\text{schedule incentive}} \right\}$$

$$+ \underbrace{\sum_{\text{term. } c} \{\Pi_{cs} - \sum_{t=t',c}^{t''-1} ts\}}_{\text{remaining unrecognized normal profit}} \equiv E_{2ts}$$

Renegotiable Costs

This is the contracts costs in each period summed over the contracts existing at that date.

$$\sum_{\text{exist } c} (\underbrace{B_{1cts}}_{\text{administrative overhead allocated to contract}} + \underbrace{B_{3cts}}_{\text{warehouse-inventory administrative overhead allocated to contract}} + \underbrace{B_{5cts}}_{\text{warehouse-inventory costs allocated to contract}} + \underbrace{B_{7tcs}}_{\text{warehouse-inventory depreciation allocated to contract}} + \underbrace{B_{9tCs}}_{\text{depreciation allocated to contract}} + \underbrace{\bar{D}_{cts}}_{\text{direct labor material}}) \equiv E_{3ts}$$

Renegotiable Profits

This is by definition

$$E_{1ts} + E_{2ts} - E_{3ts} \equiv E_{ts}$$

Renegotiable Profits As a Percentage Of Negotiable Sales

By definition, this is

$$\frac{E_{ts}}{E_{1ts} + E_{2ts}} \equiv \bar{R}_{ts}$$

This number is perceived to be upper bounded by a number subjectively set by the contractor after observing Board actions. Thus, the contract is

$$\frac{E_{1ts} + E_{2ts} - E_{3ts}}{E_{1ts} + E_{2ts}} \leqq R_{ts}$$

or

$$1 - R_{ts} \leqq \frac{E_{3ts}}{E_{1ts} + E_{2ts}}$$

Q. The Contractor's Corporate Objectives

In this section the criteria by which the contractor's management makes choices is discussed. As the reader is undoubtedly aware, there has been, and is, much controversy over whether firms maximize profits or sales or maket share or what. Williamson [12] has advocated emoluments and discretionary profit. In this paper it is hypothesized that in the defense, high technology, prime system contractor's case, a variation of Williamson's idea is appropriate.

First, there are the emoluments which take two forms. The first form is the usual idea of staff, support folks, salary and the like. Earlier this was denoted $X_{16ts}$. In addition, there is a second form which measures the value of being the "best" engineering firm "right at the edge of human knowledge." This is measured here by the planned and measured system performance variables as the time phasing dictates. These were denoted earlier as $y_{7ts}$ to $y_{Ats}$ and $z_{1ts}$ to $z_{Bts}$ depending on whether it was still planned or had been measured.

Second, it is assumed in this paper that the contractor's management is interested in maximizing profit. Further, it is assumed that the management measured profit by the only easily available measure--the corporate periodic net income. This has been denoted $EAIT_{ts}$.

Since the management is assumed to face a risky world--the states-of-nature model this idea--the usual expected utility approach is used in this paper. Thus, the actions are the net income by period ($EAIT_{ts}$), corporate emoluments ($X_{16ts}$) and system performance measures (${}_cy_{7ts}, \ldots, {}_cy_{Ats}; {}_cz_{its}; \ldots {}_cz_{Bts}$). The probability of a particular outcome or state-of-nature is assumed to be a subjective judgement of the management after looking at such facets as rivals' possible bids on future contracts, technological uncertainty, inflation expectations, regulatory actions and the general climate for defense expenditures. This probability is denoted $P_s$. Thus, the contractor's management is assumed to maximize the expected utility of variables discussed. This is written as

$$\text{Max} \sum_{s=1}^{s} P_s v([x_{16,o,s}, x_{16,1,s}, \ldots, x_{16Ts}]; [{}_cy_{70s}, {}_cy_{71s}, \ldots, {}_cy_{7Ts}], \ldots$$

$$[{}_cy_{Aos}, {}_cy_{A1s}, \ldots, {}_cy_{ATs}]; [{}_cz_{10s}, {}_cz_{11s}, \ldots, {}_cz_{1Ts}], \ldots$$

$$[{}_c z_{Bos}, \ldots z_{BTs}] ; [EAIT_{os}, EAIT_{1s}, \ldots, EAIT_{Ts}])$$

$$c=1, 2, \ldots, 14$$

In a more condensed notation

$$\text{Max} \sum_{s=1}^{s} P_s \; v([x_{16ts}] ; [y_{7ts}], \ldots [y_{Ats}] ; [z_{1ts}] \ldots [z_{Bts}] ; [EAIT_{ts}]) \quad T = 0, \ldots, T \quad c = 1, \ldots, 14$$

As this notation makes clear, the contractor's management is assumed to do subjective time discounting as well. Note that, in general, the number of the government contracts would run from $c = 1$ to $c = G$.

## R. The Defense Contractor Model

In this section all the pieces of the model discussed in the preceding section are brought together in the form of the contractor's management decision problem. The general form of this decision problem is

Max expected utility of emoluments, performance, profit

s.t.

(A) The technology of research and development

(B) The technology of test and evaluation

(C) The technology of manufacturing

(D) The technology of warehouse-inventory operations

(E) The availability of plant and equipment

(F) The availability of engineering labor

(G) The availability of engineering support labor

(H) The availability of system operators

(I) The availability of administrative labor

(J) The availability of manufacturing labor

(K) Market structure conditions

(L) Flow of funds availability

(M) Renegotiation Board actions

(N) Project costs on government contracts

Using the generic form for each type of contract, this decision problem may be written as

expected utility objective function

$$\text{Max} \sum_{s=1}^{S} P_s v([x_{16ts}];[{}_c y_{7ts}];\ldots;[{}_c y_{Ats}];[{}_c z_{1ts}]\ldots [{}_c z_{Bts}];[EAIT_{ts}]) \qquad t=0,\ldots T \quad c=1,\ldots,G$$

s.t.

research and technology

$$\text{(A)}\ H_c([{}_{cR}y_{5ts}];[{}_{cR}y_{6ts}];[{}_{cR}y_{7ts}];[{}_c y_{8ts}];\ldots [{}_c y_{Ats}];[{}_{cR}x_{1ts}];[{}_{cR}x_{2ts}];[{}_{cR}x_{7ts}]; [{}_{cR}k_{ts}];[{}_{cR}y_{4ts}];[{}_{cR}y_{3ts}];[{}_{cR}y_{2ts}]; [{}_{cR}y_{its}]) = 0 \qquad t=0,\ldots,T \quad c=1,\ldots,G \quad s=1,\ldots,S$$

test and evaluation

$$\text{(B)}\ G_c([{}_c z_{its}];\ldots[{}_c z_{Bts}];[{}_{cT}x_{15ts}];[{}_{cT}x_{14ts}];[{}_{cT}x_{13ts}] [{}_{cT}k_{ts}];[{}_{cT}x_{7ts}];[{}_{cT}y_{4ts}];[{}_{cT}y_{3ts}];[{}_{cT}y_{1ts}] = 0$$

$${}_{cR}y_{5ts} \geqq {}_{cT}y_{5ts} \qquad t=0,\ldots,T \quad c=1,\ldots,C \quad s=1,\ldots,S$$

manufacturing (C) $F_c([{}_cq_{ts}]\ ;\ [{}_{cM}y_{6ts}]\ ;\ [{}_{cM}k_{ts}]\ ;\ [{}_{cM}y_{4ts}]\ ;$

$[{}_{cM}y_{3ts}]\ ;\ [{}_{cM}y_{2ts}]\ ;\ [{}_{cM}y_{1ts}]\ ;\ [{}_{cM}x_{7ts}];$

$[{}_{cM}x_{8ts}]\ ) = 0$

$${}_cR^y{}_{6ts} \geqq {}_cM^y{}_{6ts} \qquad t=0,\ldots,T \quad c=1,\ldots,C \quad s=1,\ldots,S$$

$F_\theta([{}_\theta q_{ts}]\ ;\ [{}_{\theta M}k_{ts}]\ ;\ [{}_{\theta M}y_{4ts}]\ ;\ [{}_{\theta M}y_{3ts}]\ ;$

$[{}_{\theta M}y_{2ts}]\ ;[{}_{\theta M}y_{1ts}]\ ;\ [{}_{\theta M}y_{7ts}]\ ;\ [{}_{\theta M}x_{8ts}]\ ) = 0$

$t=0,\ldots T$

$s=1,\ldots S$

warehouse-inventory operations (D) $g_3(\bar{x}_{3ts}) + g_4(\bar{x}_{4ts}) + g_5(\bar{x}_{5ts}) + g_6(\bar{x}_{6ts}) \leqq h({}_wk_{ts})$

$$i_{x_3}(x_{3ts}) + i_{x_4}(x_{4ts}) + i_{x_5}(x_{5ts}) + i_{x_6}(x_{6ts})$$
$$+$$
$$i_{y_1}(y_{1ts}) + i_{y_2}(y_{2ts}) + i_{y_3}(y_{3ts}) + i_{y_4}y_{4ts}) \leqq$$
$$f({}_wx_{7ts}, {}_wx_{8ts}, {}_wk_{ts})$$

$$\bar{x}_{3ts} = \bar{\bar{x}}_{30s} + \sum_{t=0}^{t-1} (x_{3ts} - y_{4ts})$$

$$\bar{x}_{4ts} = \bar{\bar{x}}_{40s} + \sum_{t=o}^{t-1} (x_{4ts} - y_{3ts})$$

$$\bar{x}_{5ts} = \bar{\bar{x}}_{50s} + \sum_{t=0}^{t-1} (x_{5ts} - y_{2ts})$$

$$\bar{x}_{6ts} = \bar{\bar{x}}\ {}_{60s} + \sum_{t=0}^{t-1} (x_{6ts} - y_{1ts})$$

$$y_{its} \geqq \sum_{\text{ongoing } c \text{ and contract phase}} ({}_{cR}y_{its} + {}_{cT}y_{its} + {}_{cM}y_{its}) + {}_{\theta}y_{its} \qquad \begin{array}{l} i=2,3,4 \\ t=0,\ldots,T \\ s=1,\ldots,S \end{array}$$

$$y_{1ts} \geqq \sum_{\text{ongoing } c \text{ and contract phase}} ({}_{cR}y_{1ts} + {}_{cT}y_{1ts} + {}_{cM}y_{1ts})$$

plant and equipment (E) $$\sum_{\text{ongoing } c \text{ and contract phase}} ({}_{cR}k_{ts} + {}_{cT}k_{ts} + {}_{cM}k_{ts}) + {}_{\theta}k_{ts} + {}_{w}k_{ts} \leqq$$

$$(1-\delta)^t \bar{\bar{k}}_{10s} + \sum_{j=1}^{t} (1-\delta)^{t-j} \dot{k}_{1j-1s} + (1-\delta)^t \bar{\bar{k}}_{20s}$$

$$+ \sum_{j=1}^{t} (1-\delta)^{t-j} \dot{k}_{2j-1s} \qquad \begin{array}{l} t=0,\ldots,T \\ s=1,\ldots S \end{array}$$

engineering labor (F) $${}_{T}x_{1ts} + x_{10ts} \geqq \sum_{\text{ongoing } c \text{ in T\&E}} {}_{cT}x_{13ts}$$

$$x_{1ts} \geqq {}_{T}x_{1ts} + \sum_{\text{ongoing } c \text{ in R\&D}} {}_{cR}x_{1ts} \qquad \begin{array}{l} t=0,\ldots,T \\ s=1,\ldots,S \end{array}$$

engineering support (G) $${}_{T}x_{2ts} + x_{9ts} \geqq \sum_{\text{ongoing } c \text{ in T\&E}} {}_{cT}x_{14ts}$$

$$x_{2ts} \geqq {}_{T}x_{2ts} + \sum_{\text{ongoing } c \text{ in R\&D}} {}_{cR}x_{2ts} \qquad \begin{array}{l} t=0,\ldots,T \\ s=1,\ldots,S \end{array}$$

system operators (H) $$x_{11ts} + x_{12ts} \geqq \sum_{\text{ongoing } c \text{ in T\&E}} {}_{cr}x_{15ts} \qquad \begin{array}{l} t=0,\ldots,T \\ s=1,\ldots,S \end{array}$$

administrative labor (I) $x_{7ts} \geqq {}_w x_{7ts} + \sum_{\text{ongoing } c \text{ and contract phase}} ({}_{cR}x_{7ts} + {}_{cT}x_{7ts} + {}_{cM}x_{7ts})$

$+ {}_{\theta M}x_{7ts}$ $\quad t=0,\ldots,T$

$s=1,\ldots,S$

manufacturing labor (J) $x_{8ts} \geqq {}_w x_{8ts} + {}_{\theta M}x_{8ts} + \sum_{\text{ongoing } c \text{ in production}} {}_{cM}x_{8ts}$

$t=0,\ldots,T$

$s=1,\ldots,S$

market structure conditions (K) $x_{8ts} = q_8\ (w_{8ts})$

$x_{16ts} = q_{16}(w_{16ts})$

$x_{5ts} = q_{5ts}(w_{5ts})$

$\dot{k}_{1ts} = h_{1ts}\ (w_{k_1 ts})$

${}_\theta q_{ts} = f_\theta({}_\theta p_{ts})$ $\quad t=0,\ldots,T$

$s=1,\ldots,S$

$w_{\theta ts} = w_{\theta_1 ts}(D_{t-1,s})$

flow of funds (L) $\quad t=0,\ldots,T$

$s=1,\ldots,S$

$c=1,\ldots,C$

$$A_{1ts} = \bar{\bar{A}}_{10s} + \sum_{t=0}^{t} {}_\theta p_{t-1s}\ {}_\theta q_{t-1s} + \sum_{t=0}^{ta} \sum_{\text{ongoing } C} \beta_{cs}\ {}_c C_{t-1s} + \sum_{\text{ongoing} C} \beta_{cs}\ {}_c C_{t-1s}\Big|_{t=t_0}$$

$$+ \sum_{t=t_c}^{td} \sum_{\text{ongoing } c} \beta_{cs}\ {}_c C_{t-1s} + \sum_{\text{ongoing } c} \beta_{cs}\ {}_c C_{t-1s}\Big|_{t=t_e} + \sum_{t=t_f}^{tq} \sum_{\text{ongoing } c} \beta_{cs}\ {}_c C_{t-1s}$$

Expression for $A_{1ts}$ (cont'd)

$$+ \sum_{\text{ongoing}} \beta_{cs\ c} C_{t-1s} \Big|_{t=t_h} + \sum_{t=0}^{t} \Big\{ w_{\ell_2 ts} \dot{\ell}_{2ts} + w_{\ell_3 ts} \dot{\ell}_{3ts} - w_{0_1 ts} \dot{O}_{1ts}$$

$$- w_{k_1 t-1s} \dot{k}_{1t-1s} - \sum_{i=1}^{5,7,8,11,16} w_{it-1s} x_{it-1s} - \sum_{j=1}^{2} \phi_{js} \Big[ (1-\phi_{js})^{t-1} \bar{\bar{w}}_{\ell_3 cs} \bar{\ell}_{30s}$$

$$+ \sum_{n=1}^{t-1} (1-\phi_{js})^{t-n-1} w_{\ell_3 n-1s} \dot{\ell}_{2n-1s} \Big] - \sum_{j=1}^{2} \Big[ (1-\phi_{js})^{t} \bar{\bar{c}}_{jos} \bar{\bar{\ell}}_{jos}$$

$$+ \sum_{n=1}^{t} (1-\phi_{js})^{t} C_{jn-1s} \dot{\ell}_{jn-1s} \Big] \Big\} - \sum_{t=0}^{t} \Big\{ r_{ts}(1-r_{ts}) \Big[ {}_{\theta}p_{ts}\ {}_{\theta}q_{ts}$$

$$- \sum_{t=1}^{5,7,8,11,16} w_{its} x_{its} - \sum_{j=1}^{2} \Big( (1-\phi_{js})^{t} \bar{\bar{c}}_{jos} \bar{\bar{\ell}}_{jos} - C_{jt-1s} \dot{\ell}_{jt-1s} \Big) \Big] \Big\}$$

$$- \sum_{t=0}^{ta} \Big[ r_{ts}(1-r_{ts}) \Big\{ \sum_{\text{ongoing}} C \Big( \Big[ \frac{\beta_{cs\ c} C_{ts}}{\sum_{t=t'}^{t''} {}_c C_{ts}} \Big] \Pi_{cs} + {}_c C_{ts} \Big) - \sum_{i=2}^{4} w_{its} ( {}_{cR} y_{its}$$

$$+ {}_{cT} y_{its} + {}_{cM} y_{its} + {}_{\theta} y_{its} ) \Big\} \Big] - r_{ts}(1-r_{ts}) \Big\{ \sum_{\text{ongoing}} C \Big( \Big[ \frac{\beta_{cs\ c} C_{ts}}{\sum_{t=t'}^{t''} {}_c C_{ts}} \Big] \Pi_{cs}$$

$$+ {}_c C_{ts} \Big) - \sum_{i=2}^{4} w_{its} ( {}_{CR} y_{its} + {}_{CT} y_{its} + {}_{CM} y_{its} + {}_{\theta} y_{its} ) \Big\} \Big|_{t=t_b}$$

$$- \sum_{t=t_c}^{t_d} \Big[ r_{ts}(1-r_{ts}) \Big\{ \sum_{\text{ongoing}} C \Big( \Big[ \frac{\beta_{ts\ c} C_{ts}}{\sum_{t=t'}^{t''} {}_c C_{ts}} \Big] \Pi_{cs} + {}_c C_{ts} \Big) - \sum_{i=2}^{4} w_{its} ( {}_{cR} y_{its}$$

Expression for $A_{1ts}$ (cont'd)

$$+ \ _{CT}y_{its} + \ _{CM}y_{its} + \ _{\theta}y_{its} \Big\}\Big] - r_{ts}(1-r_{ts})\Big\{\sum_{\text{ongoing } C}\left(\left[\frac{\beta_{cs}\ _cC_{ts}}{\sum_{t=t'}^{t''} {_cC_{ts}}}\right]\Pi_{cs}\right.$$

$$\left. + \ _cC_{ts}\right) - \sum_{i=2}^{4} w_{its}(_{CR}y_{its} + \ _{CT}y_{its} + \ _{CM}y_{its} + \ _{\theta}y_{its})\Big\}\Bigg|_{t=t_e}$$

$$- \sum_{t=t_f}^{tq}\Bigg[r_{ts}(1-r_{ts})\Big\{\sum_{\text{ongoing } C}\left(\left[\frac{\beta_{cs}\ _cC_{ts}}{\sum_{t=t'}^{t''} {_cC_{ts}}}\right]\Pi_{cs} + \ _cC_{ts}\right)$$

$$- \sum_{i=2}^{4} w_{its}(_{CR}y_{its} + \ _{CT}y_{its} + \ _{CM}y_{its} + \ _{\theta}y_{its})\Big\}\Bigg]$$

$$- r_{ts}(1-r_{ts})\Big\{\sum_{\text{ongoing } C}\left(\left[\frac{\beta_{cs}\ _cC_{ts}}{\sum_{t=t'}^{t''} {_cC_{ts}}}\right]\Pi_{cs} + \ _cC_{ts}\right) - \sum_{i=2}^{4} w_{its}(_{CR}y_{its}$$

$$+ \ _{CT}y_{its} + \ _{CM}y_{its} + \ _{\theta}y_{its})\Big\}\Bigg|_{t=t_h} - \sum_{t=0}^{t} D_{ts} + \sum_{\substack{\text{ending } C \\ \text{during } t_b, t_a, t_c}}\Big[\Pi_{cs}$$

$$+ (1-\beta_{cs})\sum_{t=0}^{t''-1} {_cC_{ts}} + \ _cC_{t''s} + \ _cb_s(_c\bar{C}_s - \sum_{t=t'}^{t''} {_cC_{ts}}) + \sum_{i=1}^{B} {_c\gamma_{its}}\{_cz_{is} - \ _c\bar{z}_{is}\}$$

$$+ \ _c\varepsilon_s \sum_{t=t'}^{t''} (_cq_{ts} - \ _c\bar{q}_{ts})\Big]$$

$$
\begin{aligned}
A_{1ts} = {} & \bar{\bar{A}}_{10s} + \sum_{t=0}^{t} {}_{\theta}p_{t-1s}\, {}_{\theta}q_{t-1s} + \sum_{t=0}^{ta} \sum_{\text{ongoing } C} \beta_{cs}\, {}_{c}C_{t-1s} + \sum_{\text{ongoing } C} \beta_{cs}\, {}_{c}C_{t-1s} \Big|_{t=t_0} \\
& + \sum_{t=t_c}^{td} \sum_{\text{ongoing } c} \beta_{cs}\, {}_{c}C_{t-1s} + \sum_{\text{ongoing } c} \beta_{cs}\, {}_{c}C_{t-1s} \Big|_{t=t_e} + \sum_{t=t_f}^{tq} \sum_{\text{ongoing } c} \beta_{cs}\, {}_{c}C_{t-1s} \\
& + \sum_{\text{ongoing } c} \beta_{cs}\, {}_{c}C_{t-1s} \Big|_{t=t_h} + \sum_{t=0}^{t} \Big\{ w_{\ell_2 ts}\, \dot{\ell}_{2ts} + w_{\ell_3 ts}\, \dot{\ell}_{3ts} - w_{O_1 ts}\, \dot{O}_{1ts} \\
& - w_{k_1 t-1s}\, \dot{k}_{1t-1s} - \sum_{i=1}^{5,7,8,11,16} w_{it-1s}\, x_{it-1s} - \sum_{j=1}^{2} \phi_{js} \Big[ (1-\phi_{js})^{t-1}\, \bar{\bar{w}}_{\ell_3 cs}\, \bar{\bar{\ell}}_{30s} \\
& + \sum_{n=1}^{t-1} (1-\phi_{js})^{t-n-1}\, w_{\ell_3 n-1s}\, \dot{\ell}_{2n-1s} \Big] - \sum_{j=1}^{2} \Big[ (1-\phi_{js})^{t}\, \bar{\bar{c}}_{jos}\, \bar{\bar{\ell}}_{jos} \\
& + \sum_{n=1}^{t} (1-\phi_{js})^{t}\, c_{jn-1s}\, \dot{\ell}_{jn-1s} \Big] \Big\} - \sum_{t=0}^{t} \Big\{ r_{ts} (1-r_{ts}) \Big[ {}_{\theta}p_{ts}\, {}_{\theta}q_{ts} \\
& - \sum_{t=1}^{5,7,8,11,16} w_{its}\, x_{its} - \sum_{j=1}^{2} \Big( (1-\phi_{js})^{t}\, \bar{\bar{c}}_{jos}\, \bar{\bar{\ell}}_{jos} - c_{jt-1s}\, \dot{\ell}_{jt-1s} \Big) \Big] \Big\} \\
& - \sum_{t=0}^{ta} \Big[ r_{ts} (1-r_{ts}) \Big\{ \sum_{\text{ongoing } C} \Big( \Big[ \frac{\beta_{cs}\, {}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}} \Big] \Pi_{cs} + {}_{c}C_{ts} \Big) - \sum_{i=2}^{4} w_{its} \big( {}_{cr}y_{its} \\
& + {}_{cT}y_{its} + {}_{cM}y_{its} + {}_{\theta}y_{its} \big) \Big\} \Big] - r_{ts} (1-r_{ts}) \Big\{ \sum_{\text{ongoing } C} \Big( \Big[ \frac{\beta_{cs}\, {}_{c}C_{ts}}{\sum_{t=t'}^{t''} {}_{c}C_{ts}} \Big] \Pi_{cs}
\end{aligned}
$$

Expression for $A_{1ts}$ (cont'd)

$$+ {}_cC_{ts}\Big) - \sum_{i=2}^{4} w_{its}({}_{CR}y_{its} + {}_{CT}y_{its} + {}_{CM}y_{its} + {}_{\theta}y_{its})\Big\}\Big|_{t=t_b}$$

$$- \sum_{t=t_c}^{t_d}\Bigg[r_{ts}(1-r_{ts})\Bigg\{\sum_{\text{ongoing } C}\Bigg(\left[\frac{\beta_{ts}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]\Pi_{cs} + {}_cC_{ts}\Bigg) - \sum_{i=2}^{4} w_{its}({}_{cR}y_{its}$$

$$+ {}_{cT}y_{its} + {}_{cM}y_{its} + {}_{\theta}y_{its}\Bigg\}\Bigg] - r_{ts}(1-r_{ts})\Bigg\{\sum_{\text{ongoing } C}\Bigg(\left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]\Pi_{cs}$$

$$+ {}_cC_{ts}\Bigg) - \sum_{i=2}^{4} w_{its}({}_{CR}y_{its} + {}_{CT}y_{its} + {}_{CM}y_{its} + {}_{\theta}y_{its})\Bigg\}\Bigg|_{t=t_e}$$

$$- \sum_{t=t_f}^{tq}\Bigg[r_{ts}(1-r_{ts})\Bigg\{\sum_{\text{ongoing } C}\Bigg(\left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]\Pi_{cs} + {}_cC_{ts}\Bigg)$$

$$- \sum_{i=2}^{4} w_{its}({}_{CR}y_{its} + {}_{CT}y_{its} + {}_{CM}y_{its} + {}_{\theta}y_{its})\Bigg\}\Bigg]$$

$$- r_{ts}(1-r_{ts})\Bigg\{\sum_{\text{ongoing } C}\Bigg(\left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]\Pi_{cs} + {}_cC_{ts}\Bigg) - \sum_{i=2}^{4} w_{its}({}_{CR}y_{its}$$

$$+ {}_{CT}y_{its} + {}_{CM}y_{its} + {}_{\theta}y_{its})\Bigg\}\Bigg|_{t=t_h} - \sum_{t=0}^{t} D_{ts} + \sum_{\substack{\text{ending } C \\ \text{during } t_b, t_a, t_c}}\Big[\Pi_{cs}$$

Expression for $A_{1ts}$ (cont'd)

$$+ (1-\beta_{cs}) \sum_{t=0}^{t''-1} {}_cC_{ts} + {}_cC_{t''s} + {}_cb_s({}_c\bar{C}_s - \sum_{t=t'}^{t''} {}_cC_{ts}) + \sum_{i=1}^{B} {}_c\gamma_{its}\{{}_cz_{is} - {}_c\bar{z}_{is}\}$$

$$+ {}_c\varepsilon_s \sum_{t=t'}^{t''} ({}_cq_{ts} - {}_c\bar{q}_{ts})\Big]$$

t=0,...,T

s=1,...,S

negative indices

mean non-appearance

Renegotiation

Board

Actions

$$\text{(M)} \quad 1-R_{ts} \leq \left\langle \sum_{\substack{\text{ongoing and} \\ \text{ending contracts } c}} \left\{ \left[ \frac{cR^k_{ts} + ct^k_{ts} + cM^k_{ts}}{\sum_c (cR^k_{ts} + cT^k_{ts} + cM^k_{ts}) + \theta^k_{ts} + w^k_{ts}} \right] \right. \right.$$

$$\left[ \psi_{ts} w_{16ts} x_{16ts} + \delta \; (1-\delta)^{t-1} \bar{\bar{w}}_{k_1 os} \bar{\bar{k}}_{10s} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-1} w_{k_1 j-1s} \dot{k}_{1j-1s} \right]$$

$$+ \left[ \frac{\sum_{j=2}^{4} w_{jts}(cR^y_{jts} + cT^y_{jts} + cM^y_{jts})}{\sum_{j=2}^{4} w_{jts} y_{jts}} \right] \Big[ w_{7ts} x_{7ts} + w_{8ts} x_{8ts}$$

$$+ (\psi_{ts} x_{ts} w_{16ts} + \delta (1-\delta)^{t-1} \bar{\bar{w}}_{k_s} \bar{\bar{k}}_{1os} + \sum_{j=1}^{t-1} (1-\ )^{t-j-1} w_{k_1 j-1s} \dot{k}_{1j-1s})$$

$$\left( \frac{w^k_{ts}}{\sum_c (cR^k_{ts} + cT^k_{ts} + cM^k_{ts}) + \theta^k_{ts} + w^k_{ts}} \right) \Bigg] + w_{1ts}(cR^x_{1ts} +$$

$$+ \left[ \frac{cT^x_{13ts}}{\sum_c cT^x_{15ts}} \right] T^x_{1ts}) \quad + w_{2ts}(cR^x_{2ts}$$

$$+\left[\frac{{}_cT^x{}_{14ts}}{\sum_c {}_cT^x{}_{14ts}}\right] T^x{}_{2ts}) + w_{11ts}\left[\frac{{}_cT^x{}_{15ts}}{\sum_c {}_cT^x{}_{15ts}}\right] x_{11ts}$$

$$+ w_{7ts}({}_cR^x{}_{7ts} + {}_cT^x{}_{7ts} + {}_cM^x{}_{7ts}) + w_{8ts}\ {}_cM^x{}_{8ts}$$

$$+ \sum_{j=2}^{4} w_{jts}({}_cR^y{}_{jts} + {}_cT^y{}_{jts} + {}_cM^y{}_{jts}) \Big\}\Big\rangle$$

$$\Big\langle \sum_{\text{ongoing } c} \left(\left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]\Pi_{cs} + {}_cC_{ts}\right) + \sum_{\text{ending } c} \left({}_cb_s({}_c\bar{C}_s - \sum_{t=t'}^{t''} {}_cC_{ts})\right.$$

$$+ \sum_{i=1}^{B} {}_c\gamma_{is}({}_cz_{is} - {}_c\bar{z}_{is}) + {}_c\varepsilon_s \sum_{t=t'}^{t''} ({}_cq_{ts} + {}_c\bar{q}_{ts})$$

$$\left. + \Pi_{cs} - \sum_{t=t'}^{t''} \left[\frac{\beta_{cs}\ {}_cC_{ts}}{\sum_{t=t'}^{t''} {}_cC_{ts}}\right]\right)\Pi_{cs}\Big\rangle^{-1} \qquad \begin{array}{l} t=0,\ldots,T \\ s=1,\ldots,S \end{array}$$

project costs on government contracts

$$\text{(N)}\quad {}_cC_{ts} = w_{1ts}\left\{{}_cR^x{}_{1ts} + \left[\frac{{}_cT^x{}_{13ts}}{\sum_c {}_cT^x{}_{13ts}}\right] T^x{}_{1ts}\right\}$$

$$+ w_{2ts}\left\{{}_cR^x{}_{2ts} + \left[\frac{{}_cT^x{}_{14ts}}{\sum_c {}_cT^x{}_{14ts}}\right] T^x{}_{2ts}\right\}$$

$$+ w_{11ts}\left[\frac{{}_cT^x{}_{15ts}}{\sum_c {}_cT^x{}_{15ts}}\right] x_{11ts} + w_{7ts}({}_cR^x{}_{7ts} + {}_cT^x{}_{7ts}$$

$$+ {}_cM^x{}_{7ts}) + w_{8ts}\, {}_cM^x{}_{8ts} + \sum_{j=2}^{4} w_{jts}\,({}_cR^y{}_{jts}$$

$$+ {}_cT^y{}_{jts} + {}_cM^y{}_{jts}) + \left[\frac{{}_cR^k{}_{ts} + {}_cT^k{}_{ts} + {}_cM^k{}_{ts}}{\sum_c ({}_cR^k{}_{ts} + {}_cT^k{}_{ts} + {}_cM^k{}_{ts}) + {}_\theta{}^k{}_{ts} + {}_w{}^k{}_{ts}}\right]$$

$$\delta\left\{(1-\delta)^{t-1}\, \bar{\bar{w}}_{k_1os}\, \bar{\bar{k}}_{10s} + \sum_{j=1}^{t-1} (1-\delta)^{t-j-1}\, w_{k_1j-1s}\, k_{1j-1s}\right\}$$

$t=o,\ldots,T$

$s=1,\ldots,S$

c ongoing or ending in period t

# III. SOME FINAL THOUGHTS

## A. Specification Matters

Now that the model is specified, at least in the first version, some final thoughts are in order. As noted in chapter I, the model, as specified, contains much institutional material that is peculiar to the world of a prime system contractor and, in particular, the world of aerospace. In general, the organization and management aspects of research and development, test and evaluation, and manufacturing have been deemphasized by use of intertwined production functions without detailing the interplay of individual decisions of engineers, technicians, engineering managers, production planners, machinists, assemblers and the like. On the other hand, the financial side of the corporation including debt and equity instruments, progress payments, retained earnings and dividends has been relatively emphasized. Also, the corporation is conceived of as the holder of many defense contracts each with their own technical, production and financing problems, as well as, having commercial business of a reasonable magnitude. Thus, the model, as specified, is most useful in understanding the interplay of the phases of individual defense contracts with each other and commercial business of the corporate planning horizon as integrated by physical, accounting, and financial interrelations among them. With an understanding of such interplay and integration can come insight into the DOD acquisition process as to the behavior of contractors under various DOD acquisition policies and interfirm rivalries.

It is usual in final chapters to list the areas where the author believes that future research time might be most productive. In the case at hand, it would be expected that a list of further phenomenon should appear. While some details of individual DOD contract administration, particularly with regard to "completion-of-work" contracts come to mind, the author is sure that he is too close to the specification to see at all clearly the "forest" of research directions vice the "trees" of contract, accounting, manufacturing, financing, and many more details. Rather than such a discussion which would not seem to be particularly productive, some words need to be presented about currently planned reserach. Naturally, further thought and interaction with other researchers and practitioners should lead to a specification II at some future date. In the meantime, three areas of research based on the model, as specified, are being pursued.

In the first area will be the research which seeks to characterize the optimal decision rules for a representative defense contractor in aerospace. Such decision rules should provide an insight into what factors are important in various types of contractors' decisions, how those factors are related to one another and, finally, whether such rules can be practiced in toto or whether some decentralized decision system is practiced. This research area also includes, then, all the research relevant to the "best" decentralized procedure for reaching the optimal decision rules overall for the corporation.

In the second area is the research which seeks to predict the contractor's response to changes in factors that the contractor considers beyond control by the firm or its agents. Of major interest here is the contractor's response to changes in the various DOD control mechanisms, both as to magnitude and existence. This research and some concept of what is good or bad performance should be useful in providing policy guidance to those involved in decision making about the structure, conduct, and performance of systems acquisition process.

Finally, there is the research oriented to specific and current DOD acquisition issues. For the moment, at least, work in this area is concentrating on the response of a contractor in a world of high inflation to the varieties of DOD available "insurance" (i. e., escalation provisions), as well as, "self-insurance" in the form of "contingency pricing." Of course, other issue oriented work can be performed. Two examples of such possible work would be the contractor's response to changes in the computational methods and magnitude of progress payments and the contractor's response to DOD efforts to have the contractor invest in plant and equipment.

Reports on research efforts oriented as just discussed, as well as, by the author's colleagues and the officers enrolled at the United States Naval Postgraduate School on related systems acquisition phenomenon are and will be available as the System Acquisition Research Center Series of technical memoranda.

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